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On the Determinations of the Thermal Conductivity, Specific Heat, Density, and Thermal Expansion of Different Rocks and Refractory Materials.

By

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Reprinted from the First Report of the Laboratory of the Imperial Steel Works.

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December, 1921

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§ 1. INTRODUCTION.

Notwithstanding its utmost importance considered from both the theoretical and practical points of view, our knowledge regarding the thermal conductivity of different kinds of rocks is very imperfect. Thus we have only a few determinations for a small number of the rocks constituting our earth-crust, which have been measured by the same investigators with the same apparatus, so that their results for different rocks can be compared with each other. Further the loss of heat flowing through the walls of the furnaces, as well as, a suitable installation for the walls of electric furnaces in steel works has recently become a problem of a great importance. Thus, the determination of the physical properties of refractory materials, such as, the thermal conductivity, coefficient of thermal expansion, specific heat, density, etc, is very desirable; but there has been as yet no systematic study of these properties, especially of the thermal conductivity of refractory materials. The present investigation was commenced about four years ago in the research laboratory of the Imperial Steel Works, Yawata, to meet the above requirements, and included the determination of the diffusibility, the density and the specific heat of different rocks and refractory materials at ordinary temperature; but in the case of refractories, the same constants were also measured at high temperatures, and thus the thermal conductivity at these temperatures was calculated. In the case of refractory materials, the thermal expansion was also measured.

The thermal conductivity of the same minerals and rocks was determined by Forbes,(1) R. Weber,(2) Herschell,(3) C. Lang,(4) Lees,(5) Christiansen,(1) Hecht,(2) Yamagawa,(3) F. Neumann,(4) Murano,(5) Georgijeffski;(6) while that of refractory materials such as bricks, cements, porcelains etc, was investigated by Herschell, Lees and Chorlton,(7) and more recently by Wolodgine,(8) Dougill, Hodsman and Cobb.(9) The methods used by these investigators may be classified into two; that is, the method of measuring the conductivity in a stationary state and that of measuring the diffusibility during a periodic heating and cooling.

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(1) Forbes: Edinb. Trans. **23**, (1862), 133; **24**, (1867), 73. Proc. Edinb. Sco. **8**, (1872–1875), 62.

(2) R. Weber: Züricher Vierteljahrsschrift **23**, (1878), 209.

(3) Herschell and Lebour: Rep. Brit. Ass. (1874), (2 ; 1877), (2); (1878), 133 (1879), 158.

(4) C. Lang: Warmeleitung einiger Baumateriallen (1874).

(5) Lees: Phil. Trans. **183** A (1892) 481; Proc. Roy. Soc. **50**, 421.

As is well known, the first method, though it is very simple, does not give a very accurate result, especially in the case of an absolute determination of the conductivity. In the second method, the test-specimen is periodically heated and cooled, and the penetration of the temperature wave into its interior is measured, the diffusibility being calculated by means of Fourier's series. This method, though it gives an accurate result, is very troublesome, and therefore is not suitable for the determination of the conductivity of a large number of specimens. The measurement, however, becomes very simple, if we can obtain a heat source, whose temperature varies purely sinusoidal, instead of an arbitrary periodicity.

Let a substance having an infinite extent be bounded by a plane surface, and let the temperature at the surface vary as $v_0 \sin 2\pi t/T$

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(1) Christiansen: W. A. **14**, (1881), 23.

(2) Hecht: D. A. **14**, (1904), 1008. Diss. Königsberg (1903).

(3) Yamagawa: Jour. of Coll. of Sci. Japan, **2**, (1888), 263.

(4) F. Neumann: Ann. Chem. et. Phys. (3), **64**, (1862) 66.

(5) Murano: Rendic. R. Acc. dei Lincei (5), (1898) 7, II, 61, 83.

(6) Georgijeffski: Jour. russ. Phys-Chem. Ges. **35**, (1903) 609.

(7) Lees and Chorlton: Phil. Mag. (5), **41**, (1896), 495.

(8) Wolodgine: Bull. Societe d'Encouragement pour L'Industrie Nationale **1**, (1909), 899.

(9) Dougill, Hondsman & Cobb: Jour. Soc. Chem. Ind. **34**, No. 9, (1915).

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where v_0 is the amplitude, T the period and t the time. Then, by the theory of heat conduction, we have for the temperature v at a depth x from the surface,

$$v = v_0 e^{-x\sqrt{\frac{\pi}{kT}}} \sin\left(\frac{2\pi}{T}t - x\sqrt{\frac{\pi}{kT}}\right),$$

where $k = K/\rho c$ is the diffusibility, K, ρ, c, being the conductivity, the density and the specific heat, respectively.

If R_1, R_2 and ε_1, ε_2 be the amplitudes and phases of the temperature wave at depths x_1 and x_2 respectively, we have

$$k = \frac{\pi(x_1 - x_2)^2}{T\left(\log\frac{R_1}{R_2}\right)^2} = \frac{\pi(x_1 - x_2)^2}{T(\varepsilon_1 - \varepsilon_2)^2}.$$

Thus the diffusibility k can be calculated from the temperature-time curves observed at two different depths; either the ratio of the amplitudes or the difference of the phases can be used for the purpose in question. Then, knowing the values of ρ and c, the conductivity K can be at once deduced. Now, how can we obtain a sinusoidal periodic source of heat? This problem, which has now been solved by the present writer in a very satisfactory manner, was the object of his continuous effort during the first two years.

Four years ago, Professor K. Honda and Mr. S. Satô(1) were fairly successful in obtaining a sinusoidal periodic source of heat by periodically varying the resistance of a special construction placed in the circuit containing a heater, by means of a crank motion driven by a motor. By using this arrangement, they measured the diffusibilities of some rocks, cement and soils. But since the variation of temperature was not exactly sinusoidal, some errors may have entered into their determination of the diffusibility. Using a special form of the crank motion, R. W. King(1) also obtained a periodic source of heat of the same kind, and applied it to the determination of the diffusibility of metallic rods. From his temperature-time curves, it is also to be concluded that the variation of temperature is not exactly sinusoidal.

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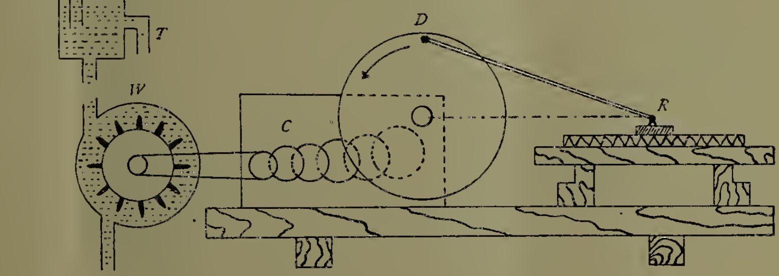
(1) Tokio Phys-Math. Soci. 2nd Series, 8, (1915-16), 424.

Working on the same principle as Professor K. Honda did, the present writer, after several fruitless attempts succeeded at last in devising a very satisfactory arrangement for obtaining a pure sinusoidal source of heat. In the following pages, the method of obtaining this kind of heat source, the arrangement for determining the diffusibility, specific heat, density and thermal expansion of different rocks and refractories will be given in order.

§ 2. A VARIABLE RESISTANCE IN A PLECTRUM FORM.

In § 3, of my former paper,(2) the mutual relation between the circular and rectilinear motions of a crank system was thoroughly studied. The utilization of the crank-system for obtaining a sinusoidal periodic source of heat is well illustrated in the sketch, Fig. 1, of the apparatus.

Fig. 1.



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(1) Phys. Rev. 2nd Series **6**, (1916) 437.

(2) Y. Tadokoro, Sci. Rep. **9**, (1920), 323.

Water wheel W is uniformly rotating under a current of water at a constant head obtained by the overflowing tank T. The velocity of this rotation is reduced to a steady slow motion by means of a series of gears in clock work C. The disc D rotates then with an extremely slow velocity; by a crank system, this motion is converted into a rectilinear motion of the end point R of the connecting rod. This last motion is availed of for moving periodically a slide contact on a variable resistance, and thus to vary periodically the electric current in the heating coil r.

Fig. 2 shows an electric connection for supplying the current in the heater. Let r and r' be the resistances of the heater and of the connecting wire respectively, and R_x that of the variable resistance included in the circuit. Then, the heat generated in the heater will be

$$\frac{re^2}{(R_x+r+r')^2},$$

e being the voltage of the battery applied.

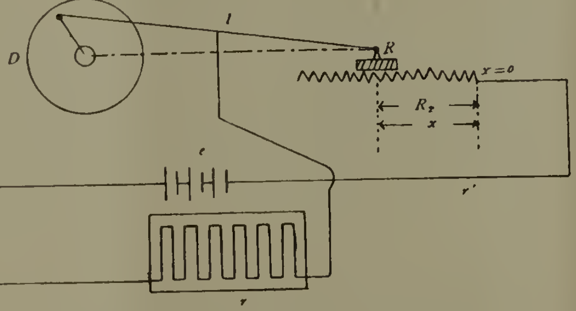
If the disc D rotates uniformly, its orientation θ is given by $\theta=\frac{2\pi}{T}t$. Hence in order to obtain a sine periodic source of heat, the following relation must be satisfied:—

$$\frac{re^2}{(R_x+r+r')^2}=p+q\sin\theta,$$

where p and q are the constants depending on the arrangement used.

The value of R_x, which is a function of x, can be found in the

Fig. 2.



following way:—Let a variable resistance be made by uniformly winding a manganin wire on a plate, whose form is to be determined.

Taking the axis of y in the direction of lines of winding, and that of x, in the direction perpendicular to it, we have

$$R_x = \frac{R_0}{A}\int_0^x y\,dx,$$

where R_0 is the total resistance and A the whole area of the plate, on which the wire is uniformly wound.

Again, p and q may be so chosen that the values $\frac{\pi}{2}$ and $\frac{3}{2}\pi$ of θ correspond to the extremities of the stroke on the variable resistance, that is,

$$p = \frac{e^2 r}{2}\left\{\frac{1}{(r+r')^2} + \frac{1}{(R_0+r+r')^2}\right\},$$

$$q = \frac{e^2 r}{2}\left\{\frac{1}{(r+r')^2} - \frac{1}{(R_0+r+r')^2}\right\};$$

hence

$$\frac{R_0}{A}\int_0^x y\,dx + r + r'$$

$$= \frac{\sqrt{2}}{\left[\left\{\frac{1}{(r+r')^2} + \frac{1}{(R_0+r+r')^2}\right\} + \left\{\frac{1}{(r+r')^2} - \frac{1}{(R_0+r+r')^2}\right\}\sin\theta\right]^{\frac{1}{2}}}.$$

Differentiating this relation with respect to x, we obtain an expression for y, that is,

$$y = \frac{1}{\sqrt{2}.\rho}\cdot\frac{\left\{\frac{1}{(r+r')^2} - \frac{1}{(R_0+r+r')^2}\right\}\cos\theta\frac{d\theta}{dx}}{\left[\left\{\frac{1}{(r+r')^2} + \frac{1}{(R_0+r+r')^2}\right\} + \left\{\frac{1}{(r+r')^2} - \frac{1}{(R_0+r+r')^2}\right\}\sin\theta\right]^{\frac{3}{2}}},$$

in where ρ is the specific resistance per unit of area. The constants, which can be suitably selected for the apparatus, are contained in the right-hand side of the above equation. Now, to express y in terms of x, we use the relation⁽¹⁾

$$\sin\theta = 1 + \frac{x(x-2l)}{2r(l+r-x)}.$$

The value $\cos\theta\,\frac{d\theta}{dx}$ can be found from the last equation by differentiating it with respect to x; that is,

$$\cos\theta\,\frac{d\theta}{dx} = -\frac{x^2+2(l+r)(l-x)}{2r(l+r-x)^2}.$$

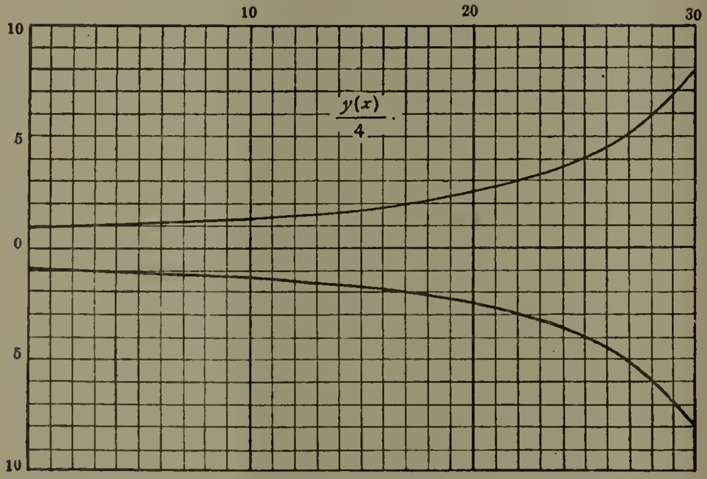
Substituting these values of $\sin\theta$ and $\cos\theta\,\frac{d\theta}{dx}$ in the expression of y, we obtain y in terms of x, that is,

$$y(x) = \frac{-1}{\sqrt{2.\rho}}$$

$$\times \frac{\left\{\frac{1}{(r+r')^2} - \frac{1}{(R_0+r+r')^2}\right\}\left\{\frac{x^2+2(l+r)(l-x)}{2r(l+r-x)^2}\right\}}{\left[\left\{\frac{1}{(r+r')^2} + \frac{1}{(R_0+r+r')^2}\right\} + \left\{\frac{1}{(r+r')^2} - \frac{1}{(R_0+r+r')^2}\right\}\left\{1 + \frac{x(x-2l)}{2r(l+r-x)}\right\}\right]^{\frac{3}{2}}}.$$

A numerical example is given in Table 1 & 2 and in Fig. 3. Here we take

Fig. 3.



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(1) Y. Tadokoro, l.c., equation (5).

$\rho = 2.0888 \times 10^{-2}\Omega$, $R_0 = 6.2664\Omega$, $r = 6{,}4\Omega$,

$r' = 0.6168\Omega$, $A = 300$ cm^2, $l = 90$ cm,

$r =$ radius of crank 15 cm.

TABLE I.

x	$-\cos\theta\frac{d\theta}{dx}$
0	0.057143
1	0.057609
2	0 058078
3	0.058564
4	0.059063
5	0.059583
6	0 060116
7	0.060666
8	0.061232
9	0.061816
10	0.062419
11	0 063041
12	0.063684
13	0.064347
14	0.065031
15	0.065741
16	0.066473
17	0.067230
18	0.068014
19	0.068826
20	0 069667
21	0.070536
22	0.071436
23	0 072372
24	0.073243
25	0.074349
26	0.075394
27	0.076479
28	0.077606
29	0.078780
30	0.080558

TABLE II.

x	$y(x)$
0	3.341910
1	3.396970
2	3.619640
3	3.773400
4	3 938700
5	4.116500
6	4.308120
7	4.515260
8	4 739640
9	4.983400
10	5.246410
11	5.563600
12	5.856360
13	6.205530
14	6.590600
15	7.083000
16	7.491900
17	7.801400
18	8.617500
19	9.290300
20	10.053300
21	11.155100
22	11.905400
23	13.169700
24	14.458700
25	16.090400
26	18.034300
27	20.419100
28	23.316200
29	27.122200
30	31.738400

§ 3. A PERFECT SINUSOIDAL SOURCE OF HEAT.

The arrangement described in Figs. 1. and 2 can be availed of for getting a sine periodic heating; but the curve of y for the variable resistance obtained in the last section is not accurate enough to obtain the pure sinusoidal heat source for a variable rotation of the disc D, as in the actual case of the crank system. Then, how can we obtain the perfect sinusoidal source of heat? The answer will be found in the following pages.

In his former paper, the present writer has discussed the relation between the time which defines the orientation of the disc D, and the position of the sliding contact R. This relation can be availed of for getting the complete plectrum-form resistance, which plays an essential part in the present problem. Now, the orientation of the disc is not given by $\theta'=\frac{2\pi}{T}t$, but by the following equation⁽¹⁾:—

$$\theta'=\omega t=\left(\theta-\frac{\pi}{2}\right)+\frac{180}{2}\int_{\frac{\pi}{2}}^{\theta}\sum_{n=1}^{10}\varphi(\theta)^n d\theta. \quad\text{..............(1)}$$

Hence, the form of the plectrum resistance obtained in the last section, is not absolutely correct for the actual case.

The exact form of the required variable resistance, using the same constants as before, is to be determined from the equations.

$$y(x')=\frac{1}{2\sqrt{2\rho . r}}$$

$$\times\frac{\left\{\frac{1}{(r+r')^2}-\frac{1}{(R_0+r+r')^2}\right\}\left\{1+\frac{l^2-r^2}{r\sin\theta+\sqrt{(l^2-r^2\cos^2\theta)}}\right\}}{\left[\left\{\frac{1}{(r+r')^2}+\frac{1}{(R_0+r+r')^2}\right\}+\left\{\frac{1}{(r+r')^2}-\frac{1}{(R_0+r+r')}\right\}\sin\theta\right]^{\frac{3}{2}}}, \quad\text{.........(2)}$$

and

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(1) Y. Tadokoro, l. c. equation (15).

$$x' = -r\sin\theta' + l + r - \sqrt{l^2 - r^2\cos^2\theta'} \quad \text{................(3)}$$

combined with equation (1). Here, $y(x')$ represents the height of the variable resistance at the position x' of equation (3) for the slider R, the relation between θ and θ' being given by the last equation (1).

Table 3 contains the values of θ', and the sliding position x', corresponding to the divisions θ of the period of the disc; from these values, (x') is calculated and given in the last column.

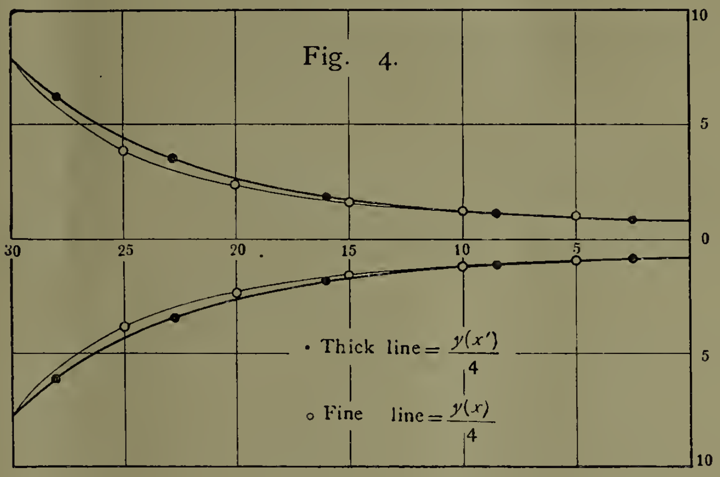


Fig. 4.

In Fig. 4, the correct form of the plectrum resistance is given in a thick line, while the fine line shows the form of the curve in the case of the uniform rotation of the disc. We see that these two curves deviate considerably from each other.

The correct plectrum resistance being thus constructed, we now proceed to describe the arrangement for obtaining the pure sine periodic source of heat.

TABLE III.

θ	θ'	x'	$y(x')$
90	90° 0′ 0″	0.0000	3.34191
95	95 39 0	0.0849	3.35035
100	101 15 0	0.3358	3.38360
105	106 33 36	0.7238	3.44660
110	111 41 24	1.2329	3.48356
115	116 48 36	1.9158	3.56521
120	121 53 24	2.6136	3.66786
125	126 45 0	3.4298	3.80113
130	131 33 36	4.3294	3.94346
135	135 22 40	5.3094	4.11986
140	141 11 42	6.3622	4.32706
145	146 0 0	7.4753	4.56726
150	150 45 0	8.6273	4.84500
155	155 30 0	9.8207	5.16498
160	160 15 36	11.0502	5.53570
165	165 0 0	12.2916	5.95345
170	169 45 0	13.5494	6.43810
175	174 30 0	14.8094	6.99170
180	179 0 0	15.9966	7.44286
185	183 41 24	17.2190	8.35435
190	188 26 24	18.4331	9.14718
195	193 7 42	19.5985	10.09800
200	197 43 36	20.7282	11.17590
205	202 31 48	21.8204	12.34530
210	207 15 0	22.8615	13.67790
215	212 3 36	23.8644	15.15780
220	216 56 24	24.8168	16.78380
225	221 51 0	25.7039	18.54260
230	226 45 0	26.5144	20.47600
235	231 41 24	27.2517	22.37260
240	236 37 48	27.9061	24.34100
245	242 0 0	28.5201	26.26030
250	247 30 0	29.0414	28.03210
255	253 7 30	29.4595	29.55780
260	258 45 0	29.7594	30.45870
265	264 22 30	29.9398	31.48650
270	270 0 0	30.0000	31.73920

§ 4. ARRANGEMENTS FOR THE EXPERIMENT.

In the preceeding discussion of the crank system, it was assumed that the disc rotates uniformly when it is free from the connecting rod. A Pelton's wheel W (Fig. 1.) running under flowing water at a constant head of about 20 metres height and with an automatic lubricating device, giving a constant friction to the moving parts, may satisfy the above requirement with a 1.5 percent deviation at the maximum. This lubricating device is obtained by means of a similar small wheel and a belt-depressor constructed to rise and fall owing to the slackening of the belt, and serves for the regular transmission of the rotation of the wheel to the gear work. When this slow uniform motion is transferred by means of an aluminium rod, 7 mm thick and 90 cm long, to the slider R, the latter moves very slowly and smoothly, as it is pressed down by a spring on the variable resistance placed on the same level as the centre of the disc D. This rectilinear periodic motion is availed of for generating a sinusoidal source of heat in the heating coil r, by varying the current in the circuit as shown in Fig. 2.

The plectrum form resistance shown in Fig. 4 is constructed by winding uniformly a manganin wire of about 8 mm thick, at an interval of 2 mm on compressed asbestos, 4 mm thick and 30 cm long, having an area of 300 cm^2. The total resistance is 6.266Ω, and therefore the resistance per square centimeter is $\rho=0.02089\Omega$. The heating coil r is also constructed by winding uniformly the manganin wire on an asbestos plate ($4\times 100\times 100$ mm^3), its total resistance being 6.400Ω.

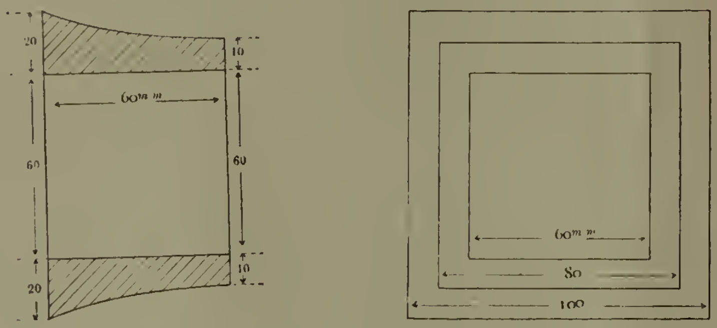
A secondary battery of a capacity of 385 ampere-hours can heat the specimen constantly at $100°C$ for over two days. The voltage applied to the circuit is 10 to 20 volts, and a thermal stationary state in the specimen is attained in 15 to 20 hours according to the case.

Two thermo-junctions are inserted in the specimen to be tested at about 10 and 40 mm respectively from the heating surface, and each of them is connected to a mirror galvanometer, and the temperature variations are observed every minute.

The specimens are tested in the form of a cube each side 60 mm. The utilization of a guard wall consisting of the same material as the specimen and placed round it is very effective in arriving at a correct result. This guard wall has a form as shown in Fig. 5, having a hollow frustum-like section, 20 mm thick at one end (heater side) and 10 mm. thick at the other. This thickness-curve along the wall was determined after many trials. The clearance between the specimen and the guard wall is 2 mm.

The general arrangement of experiment will be seen from Fig. 6, Pl. VIII. With the arrangement above described, the specimens, over one hundred in number, most of them being rocks and refractory materials, were experimented on; for all specimens, three observations were made, their mean being given as the final results in Table 4.

Fig. 5.



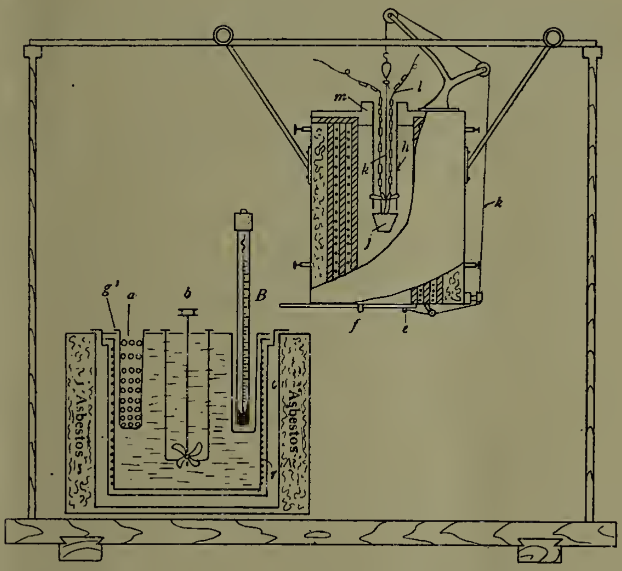
As an example, the temperature-time curves for some bricks are given in Figs. 7–13, Pl. I—VII, in which the black points represent a part of the temperature variations observed at two points in the specimen, and the full lines trace the calculated sine curves, having the same period and amplitude as the observed ones. We see that the observed temperature-time curves almost coincide with the pure sine curves.

§ 5. DETERMINATION OF SPECIFIC HEAT AND DENSITY.

Having thus far described the method of measuring the thermal diffusibility, we now proceed to explain the experiments for measuring the specific heat and density. The specific heat was determined by the usual method of mixture. The general arrangement of this experiment is seen from Fig. 14, Pl. VIII, and its plan and elevation in Figs. 15 & 16.

The calorimeter consists of a thin copper cylindrical vessel containing distilled water of 300 cc, the temperature of which is kept at 30°*C* for half an hour before each experiment, by means of a heating coil *r* with a weak current from the secondary battery. The temperature variation in the calorimeter is measured to one-thousandth of a degree by a Beckmann thermometer *B* with a reading telescope. A stirrer with four blades, made of glass, is driven by a small electric motor. The forms of the blades are so constructed as to cause circulations of the water in vertical and horizontal directions.

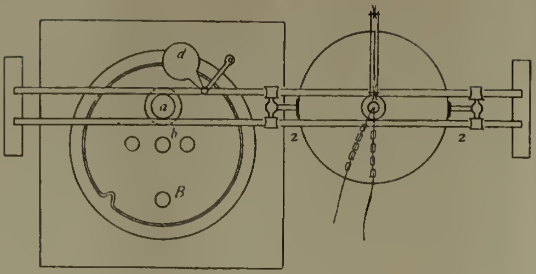
Fig. 15.



In this way, the water in the calorimeter can be well stirred; this is very important for the determination of the specific heat of the rocks and refractory materials, which are bad conductors of heat.

The cylindrical cage *a* as shown in Fig. 15 is a vessel, into which the specimen is to be dropped, and whose upper end is fitted on a soft gum

Fig. 16.



ring forming a part of the calorimeter; it is made of a thin copper plate with many holes on its lateral surface and at the bottom for free communication of heat with the outside.

Further the whole calorimeter is surrounded by another cylindrical vessel *c*, the heating coil *r* being well insulated. The calorimeter has a cover *g* made of a refractory material with three holes *a*, *B* and *b* for the cage, the thermometer, and the stirrer respectively, the first hole having a cover *d*, which can be brought over the hole by a simple rotation about an axis.

The specimens are examined in the form of very thin plates, usually 0.1 to 0.3 mm thick, so that the heat can easily be diffused in the water of the calorimeter.

The heating of the specimens is made in a vessel of platinum suspended at the centre of an electric resistance furnace, which can be rolled on rails, as seen in Fig. 15. This furnace consists of two co-axial refractory tubes; on the outer and inner tubes, platinum wires of 0.5 and 1 mm thick are anti-parabolically(1) wound. By this method of winding, a large uniform range of temperature can be obtained; that is, in a furnace of 25 cm long, 20 cm was uniform within five degree at 1000°*C*. In order to minimize the convection current as much as possible, the lower mouth of the furnace is covered with a lid *e*, which can be opened or closed by a rotation about an axis *f*; while the upper mouth is always closed by a cover *m* fitted to a tube *h* made of a refractory material, through which a thermo-junction *l* is introduced and brought in contact with the specimen.

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(1) The density of winding is inversely proportional to the length of the projection of equal arc of a parabola $y=ax^2$ on its y axis.

The vessel *j* containing the specimen is suspended by a platinum-wire *k*, 0.5 mm thick, which goes down through the tube *h* (Fig. 16). The thermo-element is of a Le Chatelier type coupled with a Siemens' millivoltmeter, calibrated at different high temperatures with pure metals from Merk. At lower temperatures, it is calibrated with a standard thermometer in a thermostat.

When the specimen is heated for over two hours at 100° *C*, and the water in the calorimeter for over half an hour at 30° *C*, the furnace containing the specimen is transferred over the cage above referred to by the rail; then the vessel containing the specimen falls automatically into the cage of the calorimeter in consequence of the slacking of the suspending wire *k* by opening the lid *e* at the lower mouth. By taking the difference between the heat quantities given out by the specimen in the platinum-vessel and by the latter alone, the loss of heat during the fall can be eliminated. As soon as the vessel falls into the calorimeter, the cover *d* is closed, the telescope read, and then the furnace is removed to its original position. These processes usually requires 5 to 6 seconds. It is found that the heat given off by radiation from the furnace during these operations has no effect on the thermometer reading. The stirrer being constantly in action, the temperature variation with time in the calorimeter is read every 15 seconds for about 10 minutes. Thus the temperature curves are taken, the initial temperature of the water in the calorimeter being maintained at 30° *C*, or 0.450 of Beckmann's thermometer, in the present experiments; the curve rises rapidly at first and reaches a maximum, after which it falls almost linearly. This portion of the curve, if produced backwards, cuts the axis of temperature at a certain height; this temperature corresponds to that at the instant of the fall of the specimen into the water, that is, to the quantity of heat received without any external loss. From the difference of the quantity of heat given out by the vessel when containing the specimen and that of the vessel alone, we can find the specific heat of the specimen by the usual formula to be refered to below.

The water equivalent of the calorimeter was determined in the way above described to be 4.29 and 4.26 by using respectively an electrolytic copper and lead from Merk, heated to 220°C, their mean specific heats being assumed to be, 0.0938 and 0.0321. Calculating approximately the water equivalent from the weights together with the specific heats of copper and glass, we obtain a value 5.73, which nearly coincides with the observed value. Hence the water equivalent was taken as 4.27 which is the mean value of the results of observation for the copper and lead. The water used in the calorimeter amounted to 300 gr; hence the above value of the water equivalent is sufficiently accurate for our purpose.

As we have observed, the specimen was always placed in a small platinum-vessel, its upper diameter being 2 cm, its bottom diameter 1 cm, its height 2 cm and its weight 3.92 gr.

The formula(1) for calculating specific heat was one introduced by Mr. I. Iitaka; that is, the mean specific heat C_{t-30} and the quantity of heat q_{t-30} between the temperature t' and 30°C were calculated by the formula

$$C_{t-30}=\frac{1}{(t-30)}\left[\frac{\partial t}{m}\left\{m'C'_{t_2-30}+C_1W+W'\right\}+C_{t_2-30}(t_2-30)\right],$$

and

$$q_{t-30}=\left[\frac{\delta t}{m}\{m'C'_{t2-30}+C_1W+W'\}+C_{t2-30}(t_2-30)\right],$$

where

t_2=temperature of the water in the calorimeter, when the vessel contains the specimen,

t=temperature to which the specimen is heated,

∂t=temperature rise of water due to the specimen; that is, the difference of temperature of water, when the vessel does and does not contain the specimen,

m=mass of the specimen,

m'=mass of the platinum-vessel,

W=mass of water in the calorimeter,

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(1) Sci. Rep. 8, (1919), 99.

W' = water equivalent of the calorimeter,

C_1 = specific heat of water between t_2 and 30°; it is assumed to be 0.9915,⁽¹⁾

C'_{t_2-30} = specific heat of the platinum between t_2 and 30° C; it is assumed to be 0.0325.⁽²⁾

With the arrangement so far described, the specific heat was determined for all specimens. For each specimen, three observations were taken and their mean was adopted as the final result. The results of measurement are given in table 4; the densities, which were measured by the usual method, are also given in the same table.

To give a general idea of the temperature variation in the calorimeter, some curves for the specimens referred to in the last section are given in the preceeding figures 7–13, Pl. I—VII.

§ 6. A CONTROL MEASUREMENT FOR THE PRESENT METHOD OF MEASURING THERMAL CONDUCTIVITY.

Though the result obtained by the present method may claim a high degree of accuracy, yet it is very desirable to check the result of the present experiment by an experiment made by another independent method.

For this purpose, a well known method of heating a cylindrical specimen by an electric current passing through its axis, was used. A long cylindrical specimen is heated by a wire, which just fits the axial hole and an electric current is passed through it; when a stationary state is reached, the total flux of heat q per unit of length of the cylinder is constant across any of the co-axial cylindrical surfaces. If the temperature at two points distant from the centre by r_1 and r_2 be denoted by t_1 and t_2 respectively, then we have

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(1) Physico-Chem. Tab. by John Castell-Evans, F. I. C., F, C. S.

(2) Ditto, 1, (1902) 185.

$$q=2\pi K\frac{t_1-t_2}{\log\frac{r_2}{r_1}}$$

where K is the conductivity of the specimen. If the length of the cylinder be l, its terminal volt E and the current through the wire i, then

$$q=\frac{Ei}{l},$$

Equating these two expressions, we get for the conductivity the following expression :—

$$K=\frac{iE.\log\frac{r_2}{r_1}}{2\pi l(t_1-t_2)}.$$

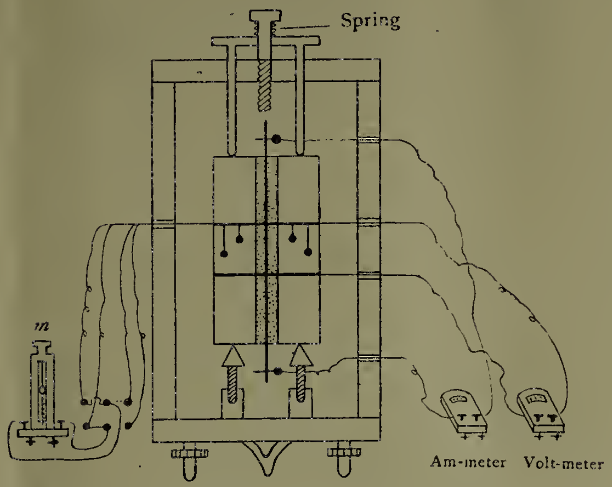
Hence, if we measure the specific heat and the density of the same material, the diffusibility can be calculated.

In the above calculation, it is assumed that the flow of heat takes place only radially; to meet this requirement, on each end of the test cylinder a guard cylinder is placed, as shown in Fig. 17. Each of the test and guard cylinders is 10 cm in diameter and 45 mm in height. The potential difference E is to be measured at the ends of the middle cylinder.

As the heating wire a carbon rod of 3 mm thick is used, the contact between the rod and the specimen being secured by filling the interspace with a powder of the same material as the specimen. A constant current from the battery is applied for several hours, before the stationary state is reached.

Two pairs of thermo-elements consisting of copper and constantan are symmetrically placed on the opposite sides of the centre in order to check the uniformity of the flow of heat from the centre outwards; it is found that heat flows uniformly from the centre in every direction,

Fig. 17.



the deviation being of the order of 1 to 2 percent at a temperature of 100° C.

The whole arrangement is shown in Fig. 17, in which *m* is the mirror galvanometer for measuring the current in the thermo-element After the stationary state has been reached, the deflections of the galvanometer, the intensity of the current and its terminal volt are observed, and the conductivity is thus deduced. The temperature difference of two points r_1 and r_2 can conveniently be measured by a deflection of the mirror galvanometer placed in the circuit of the thermo-element, the two junctions of which are placed in the two points. The results of observation for six kinds of bricks are graphically given in Figs. 7–13, together with those of the specific heat and diffusibility. For the sake of comparison, the numerical results for diffusibility and thermal conductivity for the same materials, as measured by the two different methods are given in Table 4. We see from the table that the two values of thermal conductivity almost coincide with each other.

This affords an evidence that my method of measuring the conductivity by means of a periodic source of heat is a trustworthy one.

TABLE IV.

Materials.	Thermal conductivity K directly measured.	Thermal conductivity as deduced from diffusibility.			
		Diffusibility k.	Specific heat.	Specific gravity.	$kc\rho = K$
Magnesia Brick.	0.00661	0.01485	0.206	2.006	0.00663
Chrome Brick.	0.00450	0.00820	0.172	3.200	0.00450
Silica Brick.	0.00291	0.00995	0.186	1.601	0.00297
Shamotte Brick.	0.00227	0.00648	0.188	1.916	0.00224
Common Brick.	0.00175	0.00550	0.171	1.857	0.00175
Slag Brick.	0.00107	0.00299	0.215	1.624	0.00104

Chemical analysis.

Mterials.	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	MnO	Cr_2O_3
Magnesia Brick.	22.46	2.50	14.78	4.91	......	53.27	......
Chrome Brick.	8.30	16.91	24.86	0.26	16.48	......	31.89
Silica Brick.	94.98	1.13	1.18	3.06	......	......	......
Shamotte Brick.	60.78	4.37	33.95	0.79	trace	trace	......
Common Brick.	76.52	6.77	13.67	1.77	0.42	0.27	......
Slag Brick.	26.78	6.75	15.21	43.27	......	2.20	Ign. Loss 12.60

§ 7. SOME RELATIONS BETWEEN THE THERMAL CONSTANTS MEASURED FOR DIFFERENT ROCKS AND REFRACTORY MATERIALS.

In the present investigation, extending over three years, the thermal constants for about one hundred specimen of rocks and also for some refractory materials were measured. The results are given in the following table 5. All rocks measured by the present writer were collected from different localities in our country; their chemical analysis and petrographical references will be found in the table at the end of the present paper.

If we plot the conductivities K of different rocks against their diffusibilities k as in Figs. 18, Pl. IX, it is found that the mean curve is a straight line to be expressed by an equation of the form

$$K=ak+b,$$

where a and b are constants, such as

$$a=0.6, \quad b=-0.001.$$

Again, by comparing the results of the chemical analysis of the specimens with their diffusibility or conductivity, we can find the effect of special mineral elements, such as magnesia, silica, lime and alumina, on the conductivity or the diffusibility. The examples of such a relation are given in Fig. 19, Pl. X., they show that the conductivity (curve I) or diffusibility (curve II) increases with the contents of magnesia, while it decreases with that of silica, lime, and alumina.

The effect of magnesia is almost constant up to 5 percent, and afterwards increases. In the case of lime, the conductivity or diffusibility decreases gradually; alumina causes the conductivity to decrease to 25 percent and afterwards to remain constant, silica steadily decreases it. In all cases, the variations of conductivity and diffusibility are parallel to each other, showing that the product of the density and the specific heat is not considerably affected by the presence of the mineral elements above referred to. Since old rocks have, in general, great diffusibility and conductivity, as seen in Table 4, the measurement of the thermal constants may serve for dating rocks, the ages of which are uncertain.

In the following table,

ρ=specific gravity,
c=specific heat,
k_1=diffusibility calculated from phase difference,
k_2= ,, ,, ,, amplitude ,,
$k=\frac{1}{2}(k_1+k_2)$,
K=thermal conductivity,
θ=refractoriness.

TABLE V.

FIRE BRICK.

No.	Material.	ρ	c	ρc	k_1	k_2	k	K	θ
1	Chrome Brick.	3.028	0.172	0.521	0.00753	0.00734	0.00744	0.00392	1790°c
2	Chrome Brick Powder.	2.546	0.183	0.466	0.00752	0.00733	0.00743	0.00350	1690°c
3	Magnesia Brick.	2.370	0.193	0.457	0.01156	0.01514	0.01335	0.00528	1790°c
4	Silica Brick.	1.891	0.181	0.342	0.00705	0.00728	0.00717	0.00241	1770°c
5	Silica Brick Powder.	1.708	0.190	0.325	0.00507	0.00593	0.00550	0.00197	1710°c
6	Red Brick.	1.795	0.184	0.330	0.00489	0.00503	0.00496	0.00161	1350°c
7	Red Brick (2)	1.782	0.177	0.315	0.00488	0.00528	0.00508	0.00136	1350°c
8	White Shamotte Brick.	1.565	0.177	0.277	0.00457	0.00489	0.00473	0.00125	1710°c
9	Red Shamotte Brick.	1.784	0.184	0.325	0.00487	0.00497	0.00492	0.00158	1710°c
10	Slag Brick.	1.572	0.168	0.264	0.00333	0.00364	0.00349	0.00087	1350°c
11	Slag Brick.	1.585	0.207	0.328	0.00316	0.00341	0.00329	0.00104	1350°c

ROCKS AND MINERALS.

No.	Material.	ρ	c	ρc	k_1	k_2	k	K	θ
12	Magnesite. (2)	2.948	0.214	0.631	0.03773	0.03814	0.03794	0.02381	1790°c
13	Magnesite. (1)	2.907	0.208	0.605	0.03651	0.03741	0.03696	0.02209	1790°c
14	Marble.	2.699	0.202	0.545	0.01080	0.01060	0.01070	0.00555	1790°c
15	Quartzite (Vaxiegated).	2.454	0.179	0.439	0.02946	0.03333	0.03140	0.01293	1770°c
16	Quartzite.	2.343	0.184	0.431	0.02856	0.02659	0.02758	0.01231	1810°c
17	Quartzite.	2.566	0.178	0.457	0.02408	0.02619	0.02514	0.01100	1750°c
18	Quartzite (Red).	2.450	0.183	0.448	0.02281	0.02298	0.02290	0.01025	1770°c
19	Quartzite.	2.764	0.181	0.500	0.02283	0.02254	0.02269	0.01142	1790°c
20	Quartzite.	2.523	0.179	0.452	0.01654	0.01653	0.01654	0.00749	1790°c
21	Quartzite.	2.627	0.179	0.470	0.01390	0.01364	0.01377	0.00653	1790°c
22	Quartzite.	2.734	0.201	0.550	0.01210	0.01260	0.01235	0.00666	1750°c
23	Quartzite Powder.	1.887	0.194	0.366	0.01142	0.01329	0.01236	0.00418	1750°c
24	Sand for Casting.	1.566			0.00394	0.00395	0.00395		
25	Korean "Agalmatolite."	3.141	0.201	0.631	0.01481	0.01118	0.01300	0.00935	1330°c

No.	Material.	ρ	c	ρc	k_1	k_2	k	K	θ
26	Susa "Agalmatolite."	2.947	0.200	0.589	0.01442	0.01642	0.01542	0.00849	1730°c
27	Korean "Agalmatolite."	2.867	0.208	0.596	0.01045	0.01275	0.01160	0.00623	1310°c
28	Korean "Agalmatolite."	2.566	0.224	0.575	0.01348	0.01270	0.01309	0.00775	1810°c
29	Granite.	2.654	0.183	0.486	0.01237	0.01652	0.01445	0.00601	1210°c
30	Granite.	2.612	0.179	0.468	0.01097	0.01215	0.01156	0.00513	1210°c
31	Hornblende Granite.	2.541	0.189	0.480	0.00873	0.00876	0.00875	0.04192	1190°c
32	Biotite Granite.	2.590	0.184	0.477	0.01093	0.01483	0.01288	0·00521	1270°c
33	Two Mica Granite.	2.533	0.189	0.479	0.00600	0.00608	0.00604	0.02874	1290°c
34	Granite Prophyry.	2.560	0.188	0.481	0.01185	0.01283	0.01234	0.00570	1310°c
35	Granite Gneiss.	2.496	0.185	0.462	0.01109	0.01298	0.01298	0.00512	1250°c
36	Limestone.	2.655	0.198	0.528	0.01150	0.01193	0.01172	0.00607	
37	Oslitic Limestone.	2.610	0.201	0.525	0.01016	0.01189	0.01103	0.00533	
38	Ogasawara Limestone.	2.155	0.201	0.433	0.00798	0.00799	0.00799	0.00346	1390°c
39	Coral Limestone.	2.212	0.212	0.469	0.00488	0.00487	0.00488	0.00210	1790°c
40	Tanba Limestone.	2.628	0.200	0.526	0.01016	0.01019	0.01018	0.00534	1790°c
41	Limestone.	2.672	0.185	0.496	0.01043	0.01077	0.01060	0.00515	1490°c
42	Nummulite Limestone.	2.107	0.190	0.400	0.00947	0.00953	0.00950	0.00379	1390°c
43	Shirano Limestone.	2.683	0.193	0.518	0.00994	0.01267	0.01131	0.00515	
44	Chromite.	4.128	0.167	0.689	0.00985	0.00984	0.00985	0.00679	1810°c
45	Dolomite.	2.671	0.187	0.499	0.00854	0.00839	0.00847	0.00426	
46	Hornblende-Gabbro.	2.851	0.186	0.530	0.00785	0.00787	0·00786	0.00416	1170°c
47	Basalt.	2.659	0.188	0.500	0.00689	0.00665	0.00677	0.00345	1190°c
48	Owari Clay.	1.547	0.253	0.407	0.00358	0.00327	0.00343	0.00146	1790°c
49	Hakata Clay.	1.932	0.218	0.421	0.00496	0.00477	0.00487	0.00209	1490°c
50	Raw Hakata Clay.	2.075	0.205	0.425	0.00730	0.00710	0.00720	0.00310	1490°c
51	Clay.	1.848	0.228	0.421	0.00612	0.00583	0.00598	0.00261	1770°c
52	Clay.	1.831	0.240	0.439	0.00657	0.00633	0.00645	0.00288	1690°c
53	Clay (1)	1.865	0.215	0.401	0.00611	0.00633	0.00622	0.00245	1370°c
54	Tuff....	1.552	0.223	0.346	0.00484	0.00492	0.00488	0.00168	1250°c
55	Liparite-Tuff.	2.205	0.188	0.412	0.00814	0.00802	0.00808	0.00335	1310°c
56	Liparite-Tuff.	2.271	0.194	0.441	0.00904	0.00914	0.00909	0.00399	1310°c
57	Liparite-Tuff.	2.179	0.185	0.407	0.00866	0.00857	0.00862	0.00353	1310°c
58	Tuff Breccia.	1.697	0.191	0.324	0.00522	0.00550	0.00536	0.00169	1270°c
59	Pumiceaus Tuff.	1.593	0.222	0.354	0.00414	0.00445	0.00430	0.00147	1250°c
60	Shalstein.	1.417	0.175	0.248	0.00357	0.00339	0.00348	0.00088	1230°c
61	Marl.	2.084	0.207	0.556	0.00863	0.00839	0.00851	0.00480	1430°c

No.	Material.	ρ	c	ρc	k_1	k_2	k	K	θ
62	Siliceous Sinter.	1.226	0.216	0.265	0.00388	0.00383	0.00386	0.00103	1790°*c*
63	Idzumi Sand Stone.	2.476	0.189	0.468	0.01094	0.01065	0.01080	0.00512	1270°*c*
64	Hornblende Gabbro.	2.831	0.184	0.535	0.01353	0.01283	0.01318	0.00724	1210°*c*
65	Mino Sand Stone.	2.431	0.199	0.484	0.01190	0.01189	0.01190	0.00567	1350°*c*
66	Pexidolite (Serpentine).	2.521	0.233	0.587	0.01231	0.01387	0 01309	0.00723	1370°*c*
67	Diorite.	2.671	0.189	0.505	0.01095	0.01357	0.01226	0.00553	1230°*c*
68	Sand Stone.	2.547	0.198	0.504	0.01423	0.01448	0.01436	0.00717	1150°*c*
69	Augite Porphyrite.	2.561	0.198	0.507	0.00736	0.00756	0.00746	0.00371	1190°*c*
70	Pearite.	2.145	1.237	0.508	0.00446	0.00479	0.00463	0.00227	1290°*c*
71	Rhyolite.	2.432	0.182	0.485	0 00786	0.00757	0.00772	0.00357	1290°*c*
72	Porphyrite.	2.499	0.184	0.460	0.00602	0.00605	0 00604	0.00277	1150°*c*
73	Hornblende Porphyrite.	2.718	0.198	0.535	0 00807	0.00432	0.00620	0.00432	1150°*c*
74	Porphyrite.	2.933	0.193	0.566	0.00768	0.00762	0.00765	0.00435	1190°*c*
75	Gritty Limestone.	2.456	0.211	0.519	0.00699	0.00682	0.00691	0.00363	1210°*c*
76	Kashio Gneiss.	2.520	0.192	0.484	0.00786	0.00786	0.00786	0.00381	1210°*c*
77	Volcanic Scoria.	1.080	0.180	0.194	0.00370	0.00370	0.00370	0.00072	1150°*c*
78	Shale.	2.521	0.183	0.461	0.00402	0.00402	0.00402	0.00185	1150°*c*
79	Olivin Pyroxene Andesite.	2.651	0.205	0.543	0.00564	0.00576	0.00570	0.00307	
80	Sanukite.	2.549	0.182	0.464	0 00691	0.00715	0.00703	0.00321	1170°*c*
81	Amphibolite.	2.906	0.191	0.555	0.00868	0.00861	0.00865	0.00482	1190°*c*
82	Porphyrite.	2.652	0.186	0.493	0.01739	0.01750	0.01745	0.00857	1230°*c*
83	Piemontite Schist.	2 510	0.180	0.452	0.02704	0 02738	0.02721	0.00222	1690°*c*
84	Epidote Schist.	2.890	0.186	0.538	0.00825	0.00830	0.00828	0.00444	1150°*c*
85	Talc Schist.	2.940	0.198	0.582	0.01352	0.01366	0.01359	0.00787	1210°*c*
86	Muscovite.	1.667	0.196	0.327	0.00191	0.00180	0.00185	0.00063	1590°*c*
87	Brecciated Powder.	1.825	0.227	0.415	0.01000	0.01200	0.01100	0.00415	1210°*c*
88	Asbestos....	0.0627			0.02031	0.02021	0.02026		
89	Mud Lava.	2.093	0.198	0.414	0.00465	0.00465	0.00465	0.00193	1150°*c*
90	Pyroxene Andesite.	1.509	0.201	0.303	0.00460	0.00467	0.00464	0.00139	1210°*c*
91	Ash.	0.0665			0 01560	0.01548	0.01554		
92	Ash.	1.2705			0.00353	0.00356	0.00355		
93	Loam.	1.876	0.193	0 362	0.00576	0.00592	0.00584	0.00208	1350°*c*
94	Powder of Kaolin.	0.8361			0.00563	0.00520	0.00542		
95	Lime Powder.	2.7155			0.00658	0.00658	0.00658		

MISCELLANEOUS.

No.	Material.	ρ	c	ρc	k_1	k_2	k	K	θ
96	White Porcelain.	2.357	0.190	0.448	0.00986	0.00995	0.00991	0.00442	1390°c
97	Brown Porcelain.	2.216	0.171	0.379	0.00823	0.00844	0.00834	0.00312	1450°c
98	Cement.	2.245	0.201	0.451	0.00712	0.00750	0.00731	0.00323	1210°c
99	Soil used for Casting.	1.735	0.200	0.347	0.00628	0.00605	0.00617	0.00218	1510°c
100	Soil.	1.562			0.00400	0.00332	0.00366		
101	Slag (Open Hearth Furnace).	2.419	0.163	0.394	0.00544	0.00539	0.00542	0.00214	1370°c
102	Electric Furnace Slag.	2.692	0.186	0.501	0.00609	0.00601	0.00605	0.00305	
103	Graphite Powder.	1.619	0.203	0.329	0.00665	0.00607	0.00636	0.00219	1770°c
104	Carbon Rod.	1.522	0.186	0.283	0.05220	0.05066	0.05143	0.01478	1690°c
105	Charcoal Powder.	1.397	0.217		0.00710	0.00713	0.00712	0.00214	1370°c
106	Coke Powder.	1.442	0.201	0.290	0.00788	0.00792	0.00790	0.00226	1490°c
107	Coal Powder.	1.374	0.254	0.349	0.00288	0.00273	0.00281	0.00099	1370°c
108	Glass.	2.426	0.191	0.463	0.00561	0.00549	0.00555	0.00260	
109	Cotton (Refined).	0.0403			0.02418	0.02553	0.02486		

§ 8. DETERMINATIONS OF SPECIFIC HEAT AT DIFFERENT HIGH TEMPERATURES.

The measurements of the thermal constants at ordinary temperature having been so far described, we now proceed to explain the measurements at high temperature.

The correct data of these thermal constants at high temperatures have a great importance in steel works and other industries dealing with high temperatures; but since we had almost no such data, the present writer proceeded to determine these constants for some specimens of fire bricks.

The details of the measurement of specific heat at high temperatures will be first described. In this determination, all the necessary precautions were taken, such as the preparation of water in the calorimeter containing no air, the agitation of the water automatically, eliminating the effect of the surrounding temperature, the use of very thin pieces of the specimen, 0.1 to 0.3 mm thick, etc.

The quantity of the specimen used for the experiment was usually 2 to 3 grams, according to the maximum temperature to which the specimen was to be heated, to obtain nearly the same rise of the temperature of the water in the calorimeter, as in the case of the determination of the water equivalent. The calorimeter as we have already said, contained 300 cc of distilled water.

By dropping the specimen at such a high temperature as 1000°*C* it was secured experimentally that the quantity of water in the calorimeter should not sensibly be diminished by evaporation. The time-temperature variation in the calorimeter was read every 15 seconds for about 10 minutes with an accuracy of within one thousandth degree with Beckmann's thermometer, and the temperature rise of the water, at the instant when the specimen was dropped, was obtained in the same way as before. In every case, the specimen was contained in a platinum vessel, and the temperature rise at different high temperatures due to the vessel alone was determined before-hand. From the temperature rise due to the specimen alone, we

TABEE VI.

Heating temp.	Magnesia Brick.	Chrome Brick.	Red Brick.	Shamotte Brick.	Silica Brick.
896°*C*	229.3	187.5	206.8	212.7	213.6
796	202.3	166.9	185.6	190.4	189.2
687	174.4	141.4	162.2	167.4	164.6
579	146.9	121.5	136.7	137.7	136.9
480	118.3	97.4	111.3	107.0	110.7
382	89.5	73.1	84.2	78.2	82.1
303	65.1	53.1	60.4	57.1	59.5
218	42.9	33.5	39.2	37.0	37.4

can deduce the heat quantity and the specific heat at different temperature, using the same formula as before, and as the values of C_{t_2-30} in the formula, the results given in Table 4. Three observations were taken at each temperature, and their mean taken as the final results. In Table 6, the calories contained in the unit mass of different samples at high temperatures are given.

From the calories contained in the specimen per unit mass at different temperatures, we can deduce the mean specific heat C_{t-30}, the results of which are given in Table 7 and Fig. 20, Pl. X.

TABLE VII. MEAN SPECIFIC HEAT.

Temp.	Magnesia Brick.	Red Brick.	Silica Brick.	Chrome Brick.	Shamotte Brick.
218°*C.*	0.223	0.207	0.199	0.178	0.197
303	0.238	0.221	0.218	0.195	0.209
382	0.254	0.239	0.233	0.210	0.222
480	0.263	0.247	0.246	0.216	0.238
579	0.266	0.249	0.249	0.221	0.251
687	0.265	0.247	0.250	0.219	0.255
796	0.264	0.242	0.247	0.218	0.249
894	0.263	0.237	0.242	0.215	0.241

§ 9. DETERMINATION OF THERMAL EXPANSION OR DENSITY AT HIGH TEMPERATURES.

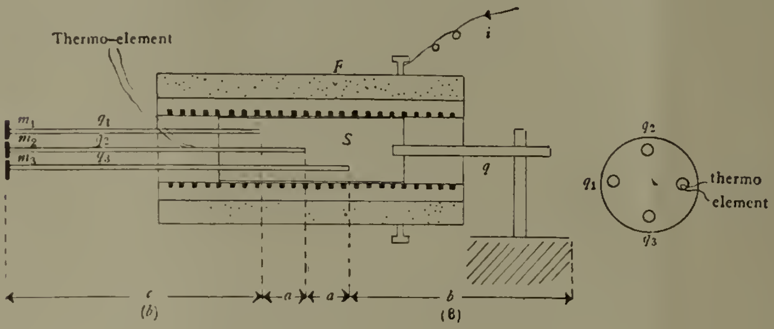
(I) Method and arrangement of experiments.

In order to know the density of refractory materials at the high temperatures, the present writer measured the thermal expansion of the specimens.

In the case of these materials, the coefficient of thermal expansion itself is a very important constant; but there is as yet no trustworthy result. The method used by the present writer is understood from Fig. 21 a, b.

Three silica tubes q_1, q_2, q_3, each having a difference of a in length, are inserted into three of four holes, which are bored parallel to the axis of the cylindrical specimen and at an angular distance of 90° from each other (Fig. 21, b). One end of the specimen is fixed in its position by means of a silica tube *q*. When the specimen is uniformly heated by an electric resistance furnace *F*, the left ends of the three silica tubes are slightly displaced which causes the rotation of the mirrors m_1, m_2 and m_3 at their ends, the amount of rotation being measured by three scales and two telescopes. The temperature of the specimen is measured by placing one junction of Le Chatelier's thermo-element in one of the four holes in the specimen.

Fig. 21 a.



If the horizontal displacements of the end of each silica tube due to a change of temperature $t-t_0$ is denoted by δl_1, δl_2 and δl_3, then we have the following relation :—

$$\delta l_1 = \delta_b + \delta_c + 2a\alpha_s(t-t_0),$$

$$\delta l_2 = \delta_b + \delta_c + a\alpha_s(t-t_0) + a\alpha_q(t-t_0),$$

$$\delta l_3 = \delta_b + \delta_c + 2a\alpha_q(t-t_0),$$

where δ_b and δ_c are the expansions of the portions *b* and *c*, α_s and α_q the expansion coefficients of the specimen and silica tube. If we take their difference, we have

$$\delta l - \delta l_2 = a(\alpha_s - \alpha_q)(t-t_0) = \delta l_2 - \delta l_3,$$

and

$$\delta l_1 - \delta l_3 = 2a(\alpha_s - \alpha_q)(t - t_0).$$

Hence

$$\alpha_s - \alpha_q = \frac{\delta l_1 - \delta l_2}{a(t - t_0)},$$

$$= \frac{\delta l_2 - \delta l_3}{a(t - t_0)},$$

and also

$$\alpha_s - \alpha_q = \frac{\delta l_1 - \delta l_3}{2a(t - t_0)}.$$

Any one of these expressions may be used equally well for the calculation of $\alpha_s - \alpha_q$, and serves as a check on the occurrence of any accidental error, in an observation. The value of α_q can be determined by a number of repeated experiments with specimens of a known coefficient of expansion, such as the electolytic copper, lead, aluminium, etc. Thus, the expansion coefficient of the silica tube used in my experiment was determined to be 0.0000026.

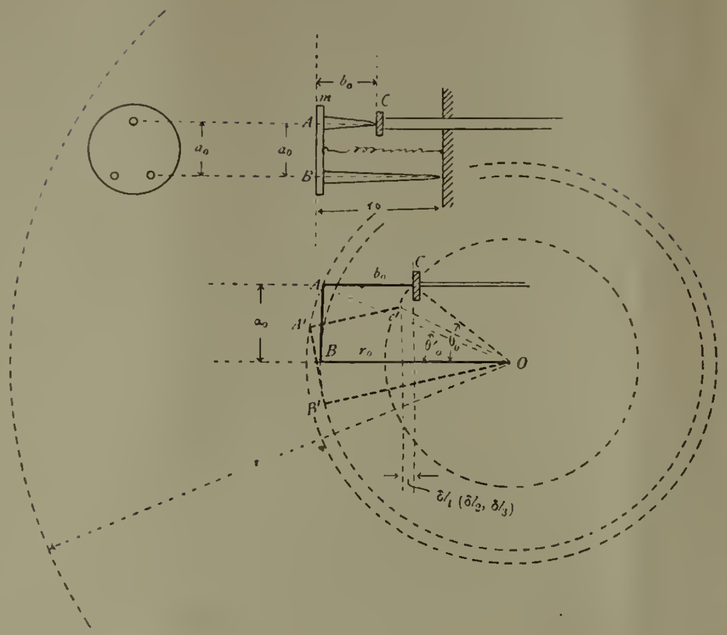
The expansion of the specimen per unit length due to the change of temperature $(t - t_0)$ will then be given by

$$\delta l_t = \alpha_s(t - t_0) = \frac{\delta l_1 - \delta l_3}{2a} + (t - t_0)\alpha q,$$

$$= \frac{\delta l_1 - \delta l_3}{2a} + 0.0000026(t - t_0).$$

Let us next find the relation between δl and the scale deflection δ_s, this scale having a circular arc of radius r, whose centre is at the lower feet of the tripod disc carrying the mirror. The mirror system is constructed as shown in Fig. 22; one foot of the mirror, length b_o, slides on a glass dise D fixed to the end of the brass bar, and other two, length r_o, rotate about the fixed point O, when the specimen is heated. Suppose now that by a rise of temperature of $t - t_0$, the ends of the silica tubes are caused to move horizontally during the expansion of the specimen, silica tube, etc.

Fig. 22.



Then, the horizontal movements will be given by the following relations :

$$\delta l_1 = \cos\theta_o \sim \cos\left(\theta_o \pm \frac{360/\delta s_1/}{4\pi r}\right),$$

$$\delta l_2 = \cos\theta_o \sim \cos\left(\theta_o \pm \frac{360/\delta s_2/}{4\pi r}\right),$$

$$\delta l_3 = \cos\theta_o \sim \cos\left(\theta_o \pm \frac{360/\delta s_3/}{4\pi r}\right).$$

where θ_o is the constant to be determined from the construction of the mirror, that is,

$$\theta = t_g^{-1}\left(\frac{a_o}{r_o - b_o}\right).$$

Hence, the expansion per unit length of the specimen due to the temperature rise $t - t_0$ will be given by

$$\delta l_t = \frac{\delta l_1 - \delta l_3}{2a} + 0.0000026(t - t_0),$$

$$= \frac{\left[\cos\left(\theta_0 \pm \frac{360/\delta s_1/}{4\pi r}\right) - \cos\left(\theta_0 \pm \frac{360/\delta s_3/}{4\pi r}\right)\right] r}{2a} + 0.0000026(t - t_0).$$

In the above equation, the positive sign represents the contraction of the specimen and the negative its expansion.

As seen from Fig. 22, during expansion and contraction, three points A, B, C of the tripod disc describe circles about O as centre and $\overline{OA}$, $\overline{OB}$, $\overline{OC}$ as radii, whose magnitudes are respectively given by

$$\overline{AO} = \sqrt{a^2_0 + r^2_0},$$

$$\overline{BO} = r_0,$$

$$\overline{CO} = \sqrt{a^2_0 + (r_0 + b_0)^2} = r.$$

In the apparatus used,

$$a_0 = 0.91 \text{ cm},$$

$$r_0 = 1.90 \text{ cm},$$

$$b_0 = 1.23 \text{ cm},$$

and therefore the numerical values of θ_0, $\overline{AO}$, $\overline{BO}$ and $\overline{CO}$ are

$$\theta_0 = \tan^{-1}\left(\frac{a_0}{r_0 - b_0}\right) = 53°33.23',$$

$$\overline{AO} = \sqrt{a^2_0 + r^2_0} = 2.111 \text{ cm},$$

$$\overline{BO} = r_0 = 1.900 \text{ cm},$$

$$\overline{CO} = \sqrt{a^2_0 + (r_0 - b_0)^2} = 1.130 \text{ cm}.$$

Using these constants, if we prepare the table for the value $\cos\left\{\theta_0 \pm \frac{360/\delta_1/}{4\pi r}\right\}$, the expansion of the specimen can be easily calculated.

Having thus far explained the principle of measuring the expansion of rocks and refractory materials, we now proceed to give the details of the apparatus used. Figs. 23, a, b represent the plan and elevation of the apparatus used. The general view is also given in Fig. 24, Pl. X. The arrangement consists of two principal parts, one of which is the heating apparatus of the specimen, and the other the appliance to indicate the change of length in the specimen, silica tube, etc.

The specimen *S* is made of a cylindrical rod, 3 cm in diameter, and 18 cm in length, having 4 small axial holes, into which the silica

Fig. 23 a.

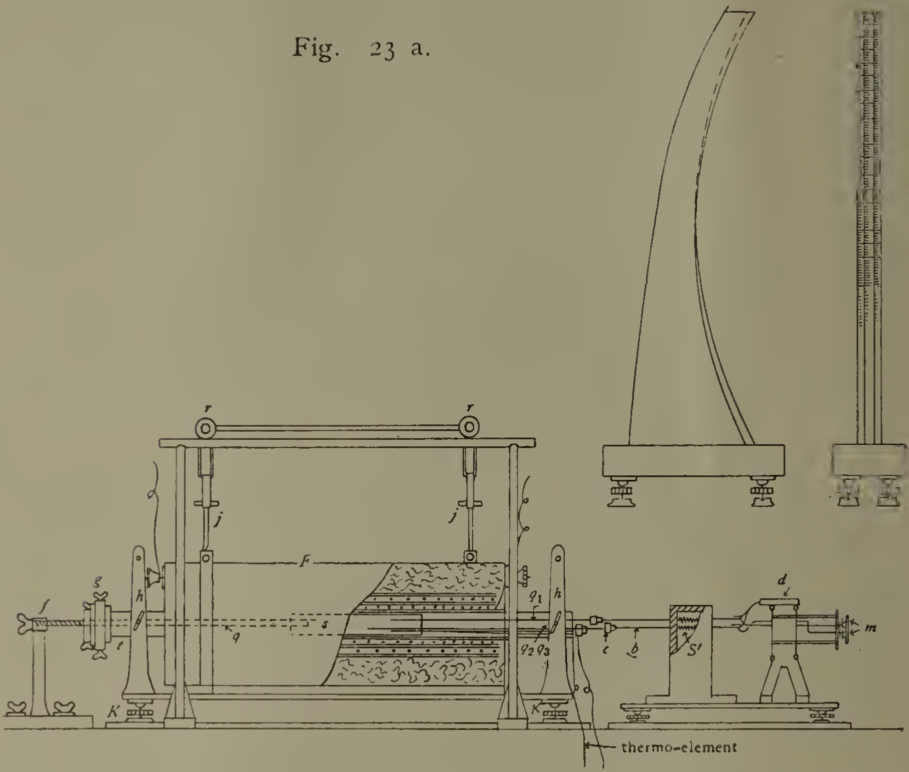
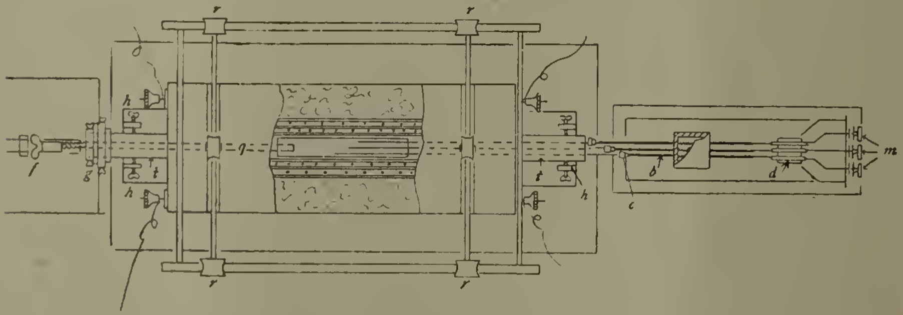


Fig. 23 b.



tubes and thermo-element can be inserted. The diameter of each hole is 5 mm, and the depths of the four holes are 3, 8, 13, 8 cm.

The electric resistance furnace *F*, 4 cm in inner diameter, consists of two coaxial refractory tubes, on which the platinum wires, 1 and 0.5 mm thick, are respectively wound antiparabolically. And thus the distribution of uniform temparature over 20 cm is obtainned for the total length of 30 cm of the furnace. As the furnace is suspended as shown in Fig. 23, a, it can be adjusted vertically by the hanger with an adjusting screw *j*, and be moved horizontally by the rolls *r* and *r'*. The protecting tube *t* made of some refractory material, 50 cm in length and 3,2 cm in inner diameter, is also adjustable both horizontally and vertically by screws *h* and *k*. When the specimen is heated uniformly, the heat will flow radially into the specimen, and therefore the temperature measured will represent that of the portion of the specimen, at which the expansion is measured. The bar *b* is pressed backwards by spring *S'*, and the mirror by spring *S''*.

The silica tubes q_1, q_2, q_3, each 2.2 mm in diameter, and 14.6, 11.6, 8.6, cm in length respectively, are connected at *c* to the brass bars *b*, 4 mm in diameter, which are guided by triangular holes *d*; the brass bars have a difference of 2 cm in length between each other.

The three mirrors, each 1 cm in diameter., are constructed as shown in Fig. 23 a and situated at the corners of an isosceles triangle, the sides being 2.4 cm and base 4.08 cm. Three arc scales are so situated that their centres of curvature coincide with the foot *O* of the tripod stand, about which the mirror rotates. The deflections of two mirrors on the same horizontal position are read by one telescope, and that of the other mirror by another telescope. The radius of curvature of the scale was 100 cm in each case. The length of the scale along the arc is 100 cm, while the total deflection is from 30 to 60 cm, when the specimen is heated to 1000° *C*.

(2) Results of experiments.

For each refractory material, three to five observations were made and their mean value was taken as the final result. The deflection-temperature curves corresponding to the three mirrors for two specimens are given in Figs. 25 & 26, Pl. XI. The curves vary irregularly with the temperature; but the expansion-temperature curves, as calculated from the equation before obtained, are found to be very smooth and run almost reversibly with the temperature (Figs. 27–32, Pl. XII—XIV).

Curves in Fig, 32, respresents the mean cnrves of heating and cooling for the true expansion of the specimen, and the numerical results are given in Tables 8 to 12.

TABLE VIII. RED-BRICK.

Temp.	Total Exp.	Exp.-Coef.	Density.
20°*C*	0.00000	0.0000000	1.857
50	0.00013	0.0000044	1.856
100	0.00036	0.0000050	1.855
150	0.00064	0.0000059	1.853
200	0.00096	0 0000067	1.852
250	0.00131	0.0000075	1.850
300	0.00171	0.0000084	1.848
350	0.00216	0.0000090	1.845
400	0.00261	0.0000087	1 843
450	0.00303	0.0000088	1 840
500	0.00350	0.0000105	1.838
550	0.00414	0.0000149	1.834
600	0 00471	0.0000078	1.831
650	0.00503	0.0000050	1.829
700	0.00526	0.0000048	1.828
750	0.00551	0.0000050	1.827
800	0.00576	0 0000051	1 825
850	0.00602	0.0000052	1.824
900	0.00630	0.0000051	1.822
950	0.00658	0 0000050	1.821
1000	0.00683	0.0000050	1.820

TABLE IX. CHROME-BRICK.

Temp.	Total Exp.	Exp.-Coef.	Density.
20° *C*	0.00000	0.0000000	2.982
50	0.00017	0.0000059	2.981
100	0.00047	0.0000070	2.978
150	0.00088	0.0000083	2.974
200	0.00132	0.0000094	2.970
250	0.00180	0.0000097	2.966
300	0.00229	0.0000099	2.962
350	0.00280	0.0000100	2.957
400	0.00330	0.0000098	2.953
450	0.00377	0.0000091	2.949
500	0.00423	0.0000090	2.945
550	0.00468	0.0000090	2.941
600	0.00512	0.0000089	2.937
650	0.00556	0.0000088	2.933
700	0.00600	0.0000088	2.929
750	0.00644	0.0000088	2.925
800	0.00687	0.0000088	2.921
850	0.00732	0.0000090	2.918
900	0.00782	0.0000090	2.913
950	0.00814	0.0000090	2.910

TABLE X. SILICA-BRICK.

Temp.	Total Exp.	Exp.-Coef.	Density.
20° *C*	0.00000	0.0000000	1.840
50	0.00071	0.0000247	1.836
100	0.00206	0.0000296	1.829
150	0.00358	0.0000279	1.820
200	0.00476	0.0000215	1.814
250	0.00575	0.0000184	1.809
300	0.00663	0.0000159	1.804
350	0.00736	0.0000133	1.800

Temp.	Total Exp.	Exp.-Coef.	Density.
400° *C*	0.00798	0.0000103	1.797
450	0.00842	0.0000085	1.794
500	0.00882	0.0000076	1.792
550	0.00918	0.0000068	1.790
600	0.00951	0.0000061	1.789
650	0.00981	0.0000054	1.787
700	0.01006	0.0000047	1.786
750	0.01028	0.0000043	1.784
800	0.01049	0.0000040	1.783
850	0.01067	0.0000036	1.782
900	0.01084	0.0000034	1.781
950	0.01102	0.0000034	1.781
1000	0.01122	0.0000034	1.779

TABLE XI. SHAMOTTE-BRICK.

Temp.	Total Exp.	Exp.-Coef.	Density.
20° *C*	0.00000	0.0000000	1.917
50	0.00024	0.0000082	1.916
100	0.00069	0.0000100	1.913
150	0.00132	0.0000181	1.909
200	0.00208	0.0000107	1.905
250	0.00249	0.0000074	1.903
300	0.00287	0.0000074	1.901
350	0.00325	0.0000076	1.898
400	0.00368	0.0000074	1.896
450	0.00405	0.0000072	1.894
500	0.00441	0.0000072	1.892
550	0.00481	0.0000094	1.890
600	0.00521	0.0000062	1.887
650	0.00551	0.0000056	1.886
700	0.00579	0.0000054	1.884
750	0.00605	0.0000053	1.883
800	0.00632	0.0000052	1.881

Temp.	Total Exp.	Exp.-Coef.	Density.
850°*C*	0.00659	0.0000053	1.880
900	0.00687	0.0000054	1.878
950	0.00716	0.0000054	1.876
1000	0.00744	0.0000054	1.875

TABLE XII. MAGNESIA-BRICK.

Temp.	Total Exp.	Exp.-Coef.	Density.
20°*C*	0.00000	0.0000000	2.295
50	0.00019	0.0000063	2.294
100	0.00054	0.0000073	2.291
150	0.00094	0.0000089	2.289
200	0.00148	0.0000131	2.285
250	0.00218	0.0000139	2.280
300	0.00288	0.0000140	2.275
350	0.00359	0.0000141	2.271
400	0.00432	0.0000142	2.266
450	0.00501	0.0000134	2.261
500	0.00567	0.0000130	2.256
550	0.00632	0.0000128	2.252
600	0.00696	0.0000126	2.247
650	0.00758	0.0000124	2.244
700	0.00822	0.0000124	2.239
750	0.00884	0.0000124	2.235
800	0.00947	0.0000125	2.231
850	0.01011	0.0000126	2.227
900	0.01078	0.0000128	2.222
950	0.01152	0.0000128	2.218
1000	0.01228	0.0000128	2·213

Table 13 contains their total expansions between 20 and 1000°*C*, and also the mean coefficients of expansion between the same range of temperature.

TABLE XIII.

	Total expansion per cm (20–1000°C).	Mean expansion coefficient (20–1000°C).	o/o of mean expansion coefficient, taking the magnesia brick as unit.
Magnesia Brick. ...	0.01230	0.00001255	100.0
Silica Brick.	0.01120	0.00001142	91.2
Chrome Brick. ...	0.00890	0.00000902	71.8
Shamotte Brick. ...	0.00748	0.00000760	60.6
Red Brick.	0.00685	0.00000700	57.6

As seen from the last column of the above table, the total expansion or the mean expansion coefficient between 29 and 1000°C of the magnesia brick is about twice that of the common red brick.

It is found from Fig. 32 that magnesia and chrome bricks expand almost linearly with temperature, though we observe some curvature at low temperatures, while in the case of the silica brick, the curve resembles that of silica in the state known as "Trydimite", and the curves for shamotte and red brick have two points, at which the curves suddenly change their directions.

The breaks in the curves for shamotte and red bricks are always found at definite temperatures for different specimens, that is, 150°C and 550°C for shamotte brick, and 550°C for red brick, though the magnitudes of the change differ from specimen to specimen.

The transformation point at 550°C, common to shamotte and red brick, is evidently due to the clay contained in them, as seen from their chemical compositions given in Table 5., and the transformation at 150°C common to shamotte and silica bricks is probably a reversible transformation of the trydimite state of the silica. These two transformations will be more clearly recognizable in Fig. 33, Pl. XVI, which represents the variation of the expansion coefficient with temperature. The same variation in the silica brick is specially marked between atmospheric temperature and 500°C, its maximum value being at 130°C; while the maximum value at 150°C for shamotte and that at 550°C for red brick are very marked.

The temperature variations of the expansion coefficient for the magnesia and chrome bricks are similar to each other; the expansion coefficient increases from room temperature to 200° *C*, remaining constant up to about 400° *C*, and then slightly diminishes for higher temperatures.

Since fire bricks have generally the transformations mentioned above, though the magnitudes differ according to their chemical compositions and heat treatments, it may be inferred that cracking, which often takes place on sudden heating and cooling, may be caused by an internal thermal stress accompanying these transformations. The crackings of silica and shamotte bricks, which are believed to occur at low temperatures, will also be explained in the same way.

For the sake of comparison, the expansion of the raw materials of silica from Dairen and Manchuria was also measured three times in succession during heating and cooling up to 1200° *C*.

The results are graphically shown in Fig. 34, Pl. XV; it is seen that in the first heating, the specimen expands to 800° *C*, and then begins to contract rapidly. During cooling, the specimen expands to 500° *C*, and then contracts rapidly. By repeated heating and cooling, the amount of the maximum expansion decreases. Thus, the heating of raw silica produces a permanent set in the specimen, the change amounting to 0.18% in the first heating, 0.135% and 0.015% in the second and third heatings respectively, in all 0.33%. For each experiment, the heating required about 4 hours, and the cooling 10 hours.

The permanent set measured at ordinary temperature is nearly the same in amount as the irreversible change produced at the transformation range.

We shall next calculate the density of the specimens at different high temperatures from the determination of the thermal expansion; the density δ_t at any temperature t is given by

$$\rho_t = \frac{\rho_0}{(1+\delta_t)^3}$$

$$= \left[1 + 0.0000026(t - t_0) + \frac{r\left\{\cos\left(\theta + \dfrac{360/\delta s_1/}{4\pi r}\right) - \cos\left(\theta \pm \dfrac{360/\delta s_3/}{4\pi r}\right)\right\}}{2a}\right]^3,$$

where ρ_0 denotes the density of the specimens at atmospheric temperature. The numerical results are given in Table 9–13, and also in Fig. 35, Pl. XVI.

TABLE XIV.

	200°*C*	300°*C*	400°*C*	500°*C*	600°*C*	700°*C*	800°*C*	900°*C*
Magnesia Brick.	0.628	0.637	0.646	0.654	0.629	0.605	0.569	0.555
Chrome Brick. ...	0.668	0.681	0.709	0.707	0.675	0.630	0.584	0.545
Silica Brick. ...	0.481	0.496	0.521	0.483	0.465	0.437	0.428	0.401
Red Brick.... ...	0.509	0.508	0.507	0.505	0.439	0.411	0.383	0.363
Shamotte Brick.	0.429	0.447	0.540	0.586	0.519	0.452	0.404	0.394

The heat capacity at different high temperatures, or the product of specific heat and density, is given in Table 14, and Fig. 36, Pl. XVII.

§ 10. DETERMINATION OF DIFFUSIBILITY AT HIGH TEMPERATURES.

(1) Method and arrangement of experiments.

For the measurement of the diffusibility at high temperatures, the same principle and apparatus as described in § 2, 3, and 4 were made use of. The arrangement (Fig. 37 a. b.) consists of the following three parts :—

(*a*) The same apparatus as before, generating a sinusoidal periodic heating ;

(*b*) The apparatus for heating the specimen to high temperatures, at which the experiment is to be made ;

(*c*) The device measuring small variations of temperature in the specimen at high temperatures.

As shown in Fig. 38, the heating apparatus consists of a stout rectangular box *B* made of brass with the lining of a refractory material, its dimensions being 31 × 21 × 21 cm.^{3} An electric resistance furnace *F* is mounted on a support *f*, and the sinusoidal heater *H*, with the specimen *S* inside, is placed within the furnace.

The furnace, 10 cm in length and 4.5 cm in inner diameter, is made of a refractory tube, on which a platinum wire, 0.5 mm thick, is wound

Fig. 37.

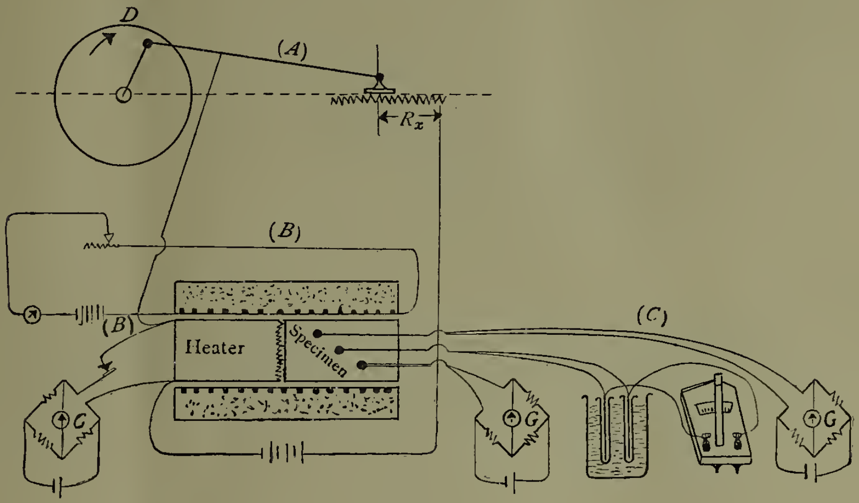
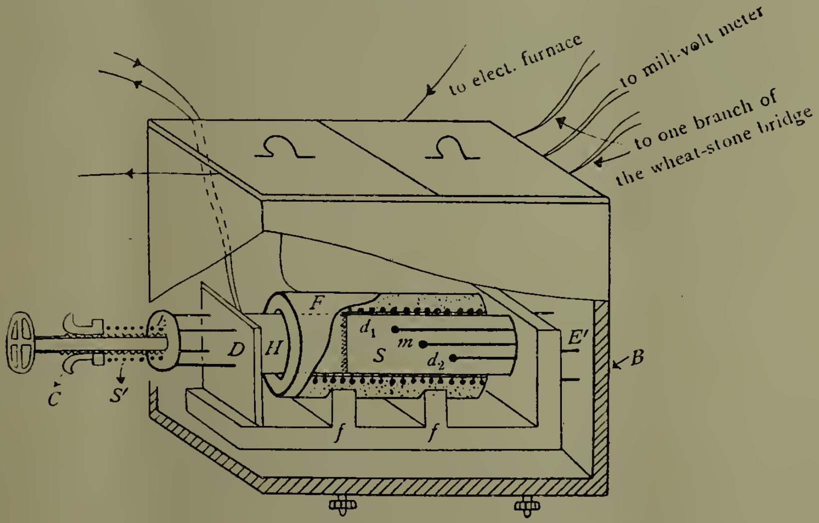
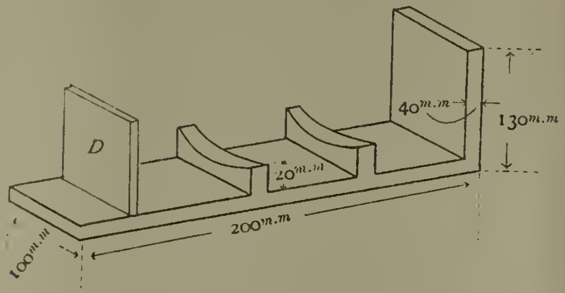


Fig. 38.



anti-parabolically, thus giving a uniform range of temperature over 8 cm with a difference of 5°*C* at 1000°*C*. The mounting of the furnace is made of a fire brick, having the form shown in Fig. 39.

Fig. 39.



The specimen is tested in a cylindrical form, 8 cm long and 4 cm thick; and the heater is 6 cm long and 4 cm in diameter. The specimen and the heater are put in sufficient contact by means of a sliding plate *D* and pressing pieces *E* and *E'*. By turning screw *C*, spring *S'* presses the sliding plate *D* against the specimen.

The heater is made of a refractory material; a platinum wire 0.11 mm thick, is uniformly wound on its end surface, which is in contact with the surface of the specimen. The resistance of the platinum wire is required to be 6.4Ω, as explained in § 2, at each temperature, at which the experiment is to be made. This was secured at each experiment by a Wheatstone bridge. The required resistance of the heater to be wound at room temperature is determined by the equation

$$l=\frac{6.4}{R_o[1+0.00158(t-t_o)]},$$

where R_o is the resistance per 100 cm at room temperature t_o, its temperature coefficient being 0.00158; Table 15 gives the relation between the temperature and the resistance of the platinum wire used :—

TABLE XV.

Temp.	Resistance.	Temp.	Resistance.
20°C	5.711 Ω	550°C	11.700
50	6.029	600	12.230
100	6.403	650	12.830
150	6.818	700	13.425
200	7.230	750	14.000
250	7.830	800	14.500
300	8.500	850	15.190
350	9.120	900	15.735
400	9.800	950	16.330
450	10.420	1000	16.930
500	11.030		

The specimen has three holes as shown in Fig. 40 at distances of 5, 15, 25 mm respectively from the contact surface with the heater, and the middle hole is used for the measurement of temperature in the

Fig. 40.

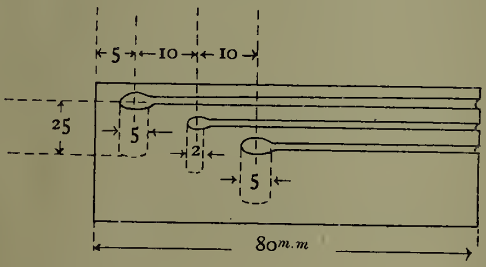
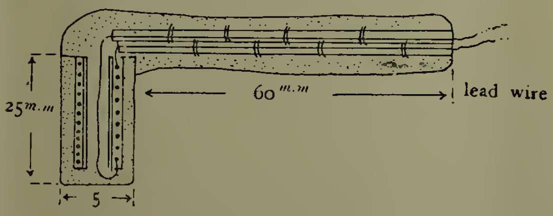


Fig. 41.

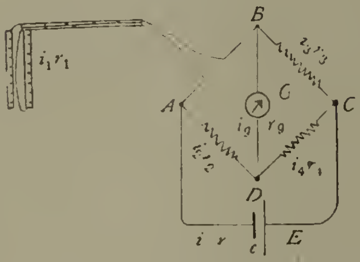


specimen by means of a thermocouple and the other two for that of the variation of temperature with a resistance thermometer as shown in Fig. 41.

This form of angled resistance is made of a refractory tube 0.2 mm in outer diameter with a hole 0.5 mm wide, on which a platinum wire, 0.11 mm thick, is wound, its resistance being about 10Ω. As we have mentioned before, the amplitude of the sine periodic variation was 3 to 5°*C*, and it was therefore necessary that some other method than the thermo-element commonly used should be applied for the measurement of a small variation at such a high temperature as 1000°*C*.

When a periodic variation of temperature is applied to the heater and a stationary state attained, the deflection of a galvanometer *G* in the Wheatstone bridge is read every minute for about 3 hours in each experiment. The relation of the deflection of the galvanometer and the variation of temperature in the specimen can easily be found in the usual way. If we take the Wheatstone bridge as shown in Fig. 42, then we have the following relations:—

Fig. 42.



At point A, $i = i_1 + i_2$

" B, $i_1 = i_3 + i_g$

" C, $i_3 = i + i_4$

" D, $i_2 = i_4 + i_g$

Round a circuit $ABCE$, $i_r + i_1 r_1 + i_3 r_3 = e$

" " $ADCE$, $i_r + i_2 r_2 + i_4 r_4 = e$

" " ABD, $i_1 r_1 + i_2 r_2 - i_g r_g = e$

Then, we have

$$i_g = i_3 - i_1 = \frac{\begin{vmatrix} e & r + r_2 + r_4 & -r_4 \\ e & r & r_3 \\ o & -r_2 & -r_5 \end{vmatrix} - \begin{vmatrix} r + r_4 & r + r_2 + r_4 & e \\ r + r_1 & r & e \\ r_1 + r_2 & -r_2 & o \end{vmatrix}}{\begin{vmatrix} r + r_4 & r + r_2 + r_4 & -r_4 \\ r + r_1 & r & r_3 \\ r_1 + r_g & -r_2 & -r_5 \end{vmatrix}}$$

$$= \frac{e(r_1 r_4 - r_2 r_3)}{a r_1 + b},$$

where a and b represent the following constants

$$a=(r+r_2)(r_3+r_4+r_g)+r_4(r_3+r_g),$$

$$b=r\{r_2(r_3+r_4+r_g)+r_2r_g+r_4r_g\}+r_2r_3r_4+r_2r_3r_g+r_3r_4r_g.$$

If the system is balanced, when the variable resistance r_1 assumes the value r_o, then we have

$$i_g=\frac{e(r_or_4-r_2r_3)}{ar_o+b}=0.$$

Since the specimen is periodically heated, the galvanometer current will be given by the following equation,

$$i_g=\frac{a'\delta t+b'}{a''\delta t+b''},$$

the variable resistance r_1 being given by

$$r_1=r_o\{1\pm\alpha\delta t\},$$

where α is the temperature coefficient of the resistance of the platinum wire, δt the temperature variation, and a', a'', b', b'' are the following constants of the bridge :—

$$a'=\alpha er_or_4,$$

$$b'=e(r_or_4-r_2r_3)=0,$$

$$a''=\alpha ar_o=r_o\alpha\{(r+r_2)(r_3+r_4+r_g)+r_4(r_3+r_g)\},$$

$$b''=b+ar_o=b+\frac{a''}{\alpha}$$

$$=r\{r^2(r_3+r_4+r_g)+r_3r_2+r_4r_g\}$$

$$+r_2r_3r_4+r_2r_3r_g+r_3r_4r_g$$

$$+r_o\{(r+r_2)(r_3+r_4+r_g)+r_4(r_3+r_g)\}.$$

In our case, the constants have the following values :—

$r_g=468\,\Omega$, $e=1.60$ volt, $r_o=10\,\Omega$, $r_8=1000\,\Omega$,

$r_3 = 100\Omega$, $r_4 = 10000\Omega$, $r = 0.08\Omega$, $a = 0.00158\Omega$;

$a' = 262.8$ $a'' = 256700$, $b'' = 1678500000$.

TABLE XVI.

δt	$i_g = \dfrac{a'\delta t}{a''\delta t + b''}$
1°C	1.50×10^{-7}
2	3.01
3	4.53
4	6.02
5	7.57
6	9.03
7	10.53
8	12.03
9	13.54
10	15.04

The result of the numerical calculation for i_g is given in Table 13 and Fig. 43, Pl. XVII. It will be seen that i_g varies almost linearly with δt; that is, the deflection of the galvanometer is proportional to the temperature variation in the specimen.

(2) Results of experiments.

With the above arrangement, the diffusibility of different refractories used in the preceding experiments was measured at different high temperatures, three to five observations at each temperature being taken.

The diffusibility was calculated by the same equation as given in § 1, taking the phase difference in the temperature-time curve at two points in the specimen into consideration; the results are given in Table 14 and Fig. 44, Pl. XVIII.

TABLE XVII.

Temp.	Magnesia Brick.	Temp.	Chrome Brick.
60° *C*	1.41×10^{-2}	60° *C*	8.20×10^{-3}
120	1.24	320	8.31
135	1.22	500	8.50
315	0.838	680	8.63
400	0.760	750	8.68
500	0.720	865	8.70
635	0.700	940	8.88
680	0.690		
766	0.685		
885	0.672		

Temp.	Silica Brick.	Temp.	Red Brick.
65° *C*	9.9×10^{-3}	65° *C*	4.88×10^{-3}
100	10.0	230	4.32
370	10.8	375	3.89
645	11.7	510	3.62
792	12.8	645	3.52
905	13.6	850	3.41
1000	14.2		

Temp.	Shamotte Brick.
68° *C*	6.40×10^{-3}
100	6.50
138	6 40
200	6.55
345	6.60
625	7.32
725	8.20
870	9.86

TABLE VIII.

Temp.	Magnesia Brick.	Chrome Brick.	Silica Brick.	Red Brick.	Shamotte Brick.
200°*C*	6.57×10^{-3}	5.55×10^{-3}	4.90×10^{-3}	2.25×10^{-3}	2.80×10^{-3}
300	5.47	5.71	5.25	2.08	2.95
400	4.91	5.99	5.68	1.94	3.59
500	4.71	6.01	5.41	1.85	3.96
600	4.39	5.79	5.35	1.56	3.69
700	4.14	5.45	5.29	1.44	3.39
800	3.85	5.10	5.48	1.32	3.69
900	3.73	4.77	5.41	1.23	4.02

As seen from Fig. 44, the diffusibility of magnesia and common red bricks decreases with temperature, especially in the case of the former which rapidly decreases to 400°*C* and then gradually decreases. For silica, shamotte and chrome bricks, the diffusibility increases with temperature. In the first two the diffusibility increases almost linearly with temperature up to about 500°*C*, and afterwards somewhat rapidly, while in the last specimen, it increases slightly. Hence it is concluded that silica bricks are most suitable for installation of a reservoir of heat, the temperature of which is required to rise as quickly as possible, when hot gas come into it, and to cool quickly, when cold air come in.

The thermal conductivity at high temperature can be calculated from heat capacity as given in Table 15, and the diffusibility, as given in Table 17. The results are given in Table 16 and Fig. 45, Pl. XIX. The conductivities of magnesia and red bricks decrease with the rise of temperature, while those of chrome, silica and shamotte bricks increase at first, pass through a maximum, and then decrease, with the rise of temperature. In the last two specimens, above 700°, an increase of conductivity is observed. It is also concluded that shamotte bricks are most suitable for installation, where thermal insulation is required, this property coinciding with the fact generally recognized by practical workmen. It is also to be seen from Fig. 45 that the variation of conductivity between 400° and 550°*C* is, as in other thermal properties, abnomral for shamotte and silica bricks.

In conclusion, the present writer expresses his hearty thanks to Professor K. Honda, who has shown a great interest in the present investigation and given unceasing and invaluable advice throughout the course of the present experiments extending over three years, and to Professor T. Hayashi, Director of the Science Department of Tôhoku Imp. Univ., who has given constant encouragement to the writer, as well as to Professor M. Kawamura for kindly giving so many petrographical references regarding the specimens used in these experiments.

June, 1920.

Petrographical References of the Specimens used in the Present Experiment.

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1. Chrome brick.

This test-piece is one of the foreign manufactures.

C. A. (Chemical analysis):—
SiO_2 = 1.88 Fe_2O_3=1.843 MgO =14.56
Al_2O_3=19.51 CaO =0.94 Cr_2O_3=36.42

2. Chrome brick powder.

The test piece is made of the powder of chrome brick burned at the temperature of Seger's No. 12 and pressed into the desired form.

C. A:—
SiO_2 =21.80 Fe_2O_3=13.67 MgO =12.47
Al_2O_3=30.12 CaO = 0.086 Cr_2O_3=19.47

3. Magnesia brick.

The test piece is made in Imperial Steel Works, the raw material being imported from Manchuria.

C. A:—
SiO_2 =18.26 Fe_2O_3= 0.80 CaO =trace
Al_2O_3= 2.56 MgO =76.43 MnO=0.21

4. Silica brick.

This test piece is one of those made in the Imperial Steel Works of Japan, and tested before using in furnace.

C. A:—
Al_2O_3=1.27 CaO =2.80 SiO_2=91.20
MnO =0.46 Fe_2O_3=4.01

5. Silica brick powder.

Locality.—Prov. Chikuzen. (筑前國). The test piece is made by pressing the powder of the silica brick prepared from the white quartzite burned at the No. 12 of the Seger's cone.

C. A:—
SiO_2 =72.82 Fe_2O_3=trace CaO =0.94
Al_2O_3=25.63 MgO =trace MnO=trace

6. Red brick.

The test piece is cut from the red brick commonly used for building.

C. A:—
Al_2O_3=21.96 MgO =trace SiO_2=76.32
CaO =trace Fe_2O_3=1.88

7. Red brick (2).

The test piece is made from the red brick as before.

C. A:—
Al_2O_3 = 21.13 MgO = trace SiO_2 = 76.45
CaO = trace Fe_2O_3 = 2.02

8. White shamotte brick.

The test piece, as well as several following other specimens, are from Imperial Steel Works.

C. A:—
Al_2O_3 = 19.48 MgO = trace SiO_2 = 79.98
CaO = trace Fe_2O_3 = 0.40

9. Red shamotte brick.

To be referred to (19).

C. A:—
Al_2O_3 = 25.56 MgO = 0.53 SiO_2 = 71.74
CaO = 0.82 Fe_2O_3 = 1.02

10. Slag brick.

To be referred to (19).

C. A:—
SiO_2 = 26.34 Fe_2O_3 = 0.26 CaO = 40.39
Al_2O_3 = 12.90 MgO = 0.34 MnO = 1.71
Loss on ign. = 16.23

11. Slag brick.

To be referred to (19).

C. A:—
Fe_2O_3 = 0.28 SiO_2 = 25.64 MgO = 0.4
MnO = 2.09 Al_2O_3 = 13.72 CaO = 41.32
Loss on ign. = 15.81

12. Magnesite (2).

Locality—Kwantung, Manchuria. This material is imported from Kwantung, Manchuria, and used for the making of magnesia brick. Metamorphosed sedimentary rock of paleozoic group, greatly resembliding coarse crystalline marble, essentially of magnesite, individual crystalline grains ranging between 7–0.3 mm; talc and graphitic substance occur as accessory constituents, the former filling interstices of crystalline grains of magnesite, and the latter forming thin veins parallel to the bedding plane; holes for the thermometers bored in the test piece are parallel to the bedding plane, the direction connecting the holes being perpendicular to the plane.

C. A:—
SiO_2 = 4.32 Fe_2O_3 = 0.96 $CaCO_3$ = trace
Al_2O_3 = trace $MgCO_3$ = 94.14

13. Magnesite (1)

Locality—Kwantung, Manchuria. The same as the above; structure somewhat brecciated, bedding plane marked by the pressure of graphitic substance being curved and broken; holes for the thermometers bored parallel to the bedding plane, the direction connecting the holes being also parallel to it; incipient cracks present; essentially of magnesite, individual grains ranging in size between 15–1 mm; talc, serpentine, and graphitic substance occur as accessory constituents.

C. A:—

Al_2O_3 = trace $CaCO_3$ = trace SiO_2 = 5.4
$MgCO_3$ = 94.14 Fe_2O_3 = 1.94

14. Marble.

Locality.—Prov. Mino. (美濃國不破郡赤坂町).—Colour white; a member of paleozoic group.

C. A:—

Al_2O_3 = 1.55 MgO = 0.39 SiO_2 = 0.29
$CaCO_3$ = 96.02 Fe_2O_3 = 0.49

15. Quartzite (Variegated).

Locality—Prov. Bungo. (豐後國北海部郡).—This quartzite is to be used for the making of silica brick. Metamorphosed sedimentary rock of paleozoic group: variegated in red and white, texture very fine, no trace of bedding plane with distinct brecciated structure; red portion is of intimate mixture of submicroscopic quartz and hematite, while the white portion is of quartz, the latter being the origin of the former, and coarser in texture, the grains reaching 3 mm in diameter.

C. A:—

Al_2O_3 = 1.13 $CaCO_3$ = trace SiO_2 = 95.62
Fe_2O_3 = 2.95

16. Quartzite.

Locality.—Prov. Chikuzen. (筑前國田川郡). Colour white; this material is to be used for the making of silica brick as before.

C. A:—

CaO = 0.28 SiO_2 = 98.34 Fe_2O_3 = 1.32

17. Quartzite.

Locality.—Prov. Chikuzen. (筑前國企救郡松ヶ江村). This quartzite is to be used for making silica brick. Metamorphosed sedimentary rock of paleozoic group; no bedded structure; colour light grey; essentially of quartz; no accessory constituents worth mention, except minute inclosures (0.015–0.005 mm) of indeterminable nature; microscopically shows honey-comb-structure, granularity ranging between 3.0–0.05 mm.

C, A:—

SiO_2 = 93.96 Fe_2O_3 = 2.68 CaO = 0.47
MgO = trace MnO = 0.54 Al_2O_3 = 2.02

18. Quartzite (Red).

Locality.—Prov. Bungo. (豐後北海部郡). This quartzite is to be used for making silica brick; and metamorphosed sedimentary rock of paleozoic group, dark red coloured; texture very fine; no trace of original bedding plane; fine veins of chalcedonic appearance and angularly bounded red colour portion occurring in the grey coloured chalcedonic matrix give the effect of brecciated structure; essentially of quartz which reaches 0.3 mm in vein portions, but sinks down to submicroscopic size in others; hematite sericite, and epidote occur as accessory constituents.

C. A:—

$SiO_2=92.79$ $Fe_2O_3=2.26$ $Al_2O_3=3.26$

$CaO= 1.38$

19. Quartzite.

Locality.—Kwantung, Manchuria. Also to be used for making silica brick; metamorphosed sedimentary rocks of paleozoic group; colour greyish white; no trace of bedding plane; grains of quartz megascopically observed; essentially of quartz; muscovite, kaolinite, and limonite as accessory components; partly rounded and partly angular grains of quartz not exceeding 0.7 mm in diameter cemented with quartz that shows finely mozaic structure, the diameter being about 0.05–0.01 mm; mica present often in contact with the original surface of the quartz sand; no instance of crystalline continuity between the sand and cement observed; original quartz shows strain shadows and its margin is often seen mylonitized and passing off gradually to the secondary quartz

C. A:—

$Al_2O_3=0.52$ $SiO_2=96.16$ $Fe_2O_3=2.68$

20. Quartzite.

Locality.—Prov. Hizen. (豐前國). The material is to be used for making of the silica brick, metamorphosed sedimentary rock of paleozoic group; colour light grey with bluish green tinge; texture very fine; no trace of bedding plane; essentially of quartz; calcite and chloritic substance present as accessory constituents; microscopically shows fine mozaic structure, individual grains of quartz ranging mostly between 0.92–0.005 mm; fine veins of quartz abundant; in vein portions the quartz is at coarser texture (0.5–0.05 mm), calcite and chloritic substance also occur in fine wavy veins.

C. A:—

$SiO_2=94.43$ $Fe_2G_3 =1.77$ $CaO =0.85$

$MgO= 0.39$ $CaO(Cu)=$trace $Al_2O_3=2.28$

21. Quartzite.

Locality.—Kwantung, Manchuria. Colour greyish white; metamorphosed sedimentary rock of paleozoic group.

C. A:—

$SiO_2=94.56$ $Fe_2O_3=2.15$ $Al_2O_3=0.90$

$CaO= 1.84$

22. Quartzite.

Locality.—Kwantung, Manchuria. This test piece as well as (41) are made of the materials from Nwantung, and used for making silica brick; colour greyish white; metamorphosed sedimentary rock of paleozoic group.

C. A :—
$SiO_2 = 91.4$ $Fe_2O_3 = 2.92$ $CaO = 0.47$
$MgO = 0.21$ $MnO = 0.92$ $Al_2O = 2.75$

23. Quartzite power.

Locality.—Prov. Chikuzen. (筑前國). The test piece is made of the powder of white quartzite prepared for casting mould.

C. A :—
$SiO_2 = 93.66$ $Fe_2O_3 = 3.48$ $Al_2O_3 = 1.40$
$MgO = 0.65$

24. Sand for casting.

The test piece is also made by putting the sand for casting in a cubical box of wood.

25. Korean " Agalmatolite "

Locality. Korea. (慶尙北道). This material, is to be used for making so called " Roseki " fire brick; colour dark red; irregularly banded structure observed; direction of conductivity measurement nearly parallel to the plane of bedding; hametite, though known as " Agalmatolite," nearly 30% is of hematite of globular form (0.02 mm ; talcosite and amorphous substance of probably similar composition compose the essential part; microtexture very fine, except grains of quartz which occur sporadically and reach sometimes millimeter size; fragment of what seems to have been ground mass of acid porphyritic rock also occur sporadically.

C. A :—
$SiO_2 = 62.23$ $Fe_2O_3 = 28.21$ $Al_2O_2 = 38.47$
$CaO = 0.28$

26. Susa " Agalmatolite "

Locality.—Prov. Nagato. (長門國阿武郡須佐). The material is to be used for making same brick as before; colour cream-white; finely brecciated structure observed; though known as " Agalmatolite " almost 60% is of quartz, it being the only mineral constituent that can be determined microscopically; what seems to have been phenocryst of quartz is present, pointing rock of rhyolite series.

C. A :—
$SiO_2 = 83.23$ $Fe_2O_3 = 3.18$ $Al_2O_3 = 12.81$
$CaO = 0.30$

27. Korean " Agalmatolite."

Locality.—Korea. (慶尙北道). To be referred to remarks for (39), having many points in common.

C. A :—
$Al_2O_3 = 28.63$ $SiO_2 = 41.15$ $Fe_2O_3 = 29.69$

28. Korean " Agalmatolite."

Locality.—Korea. (慶尙北道). To be referred to (39), the test piece being made of similar material as (39), but differing in the specific gravity and refractoriness.

C. A:—

$Al_2O_3=42.52$ $SiO_2=57.17$ $Fe_2O_3=$trace

29. Granite.

Locality.—Prov. Nagato. (長門國). The test piece is unfortunately prepared from a specimen having "Schlieren"; the holes for the thermometers are bored in the "Schlieren"—side, the bottom of holes, however, reaching granite portion; essentially of quartz, orthoclase, perthite, acid plagioclase, biotite, and hornblende, accessory constituents being apatite; felspar ranges in size between 7–0.5 mm, quartz between 5–0.3 mm, and biotite and hornblende between 1–0.1 mm; "Schlieren" portion which occupies one half in volume of the test piece is very dark coloured and of quartz, plagioclase, biotite, and hornblende; orthoclase present very sparingly, while biotite and hornblende occupy nearly 25% of volume; apatite as accessory constituents; texture very fine, individual crystals mostly smaller than 0.5 mm in diameter.

C. A:—

$SiO_2=69.62$ $Fe_2O_3=6.55$ $CaO=3.75$
$Al_2O_3=15.37$ $MgO=0.87$ $MnO=0.37$

30. Granite.

Locality.—Prov. Settu. (攝津國武庫郡本山村). Essentially consisting of quartz, orthoclase, biotite, and hornblende; magnetite and apatite present sparingly as accessory constituents, orthoclase is greatly kaolinized, megascopically slightly pink coloured and clayey in apparance.

C. A:—

$SiO_2=75.08$ $Fe_2O^3=0.63$ $CaO=2.30$
$Al_2O_3=15.60$ $MgO=$trace $MnO=0.64$
$FeO=2.79$

31. Hornblende Granite.

Locality.—Prov. Mikawa. (三河國設樂郡片山村). Essentially composed of quartz, orthoclase, plagioclase, biotite, and hornblende, most of them ranging in size between 5.0–1.0 mm; long prismatic crystals of hornblende often measure 8 mm in length; felspars are partly altered to kaoline sericite, and saussurite; biotite altered partly to chlorite.

C. A:—

$SiO_2=65.00$ $Fe_2O_3=4.58$ $CaO=6.14$
$Al_2O_3=16.48$ $MgO=3.09$ $FeO=4.68$

32. Biotte Granite.

Locality.—Prov. Yamashiro. (山城國相泉郡笠置村). Essentially consisting of quartz, orthoclase, acid plagioclase, and biotite; feldspars not kaolinized; even grained and coarse in texture, grains of component minerals ranging mostly between 10–2 mm.

C. A:—

$Fe_2O_3=0.80$ $FeO=2.28$ $SiO_2=74.96$
$MnO=0.23$ $Al_2O_3=16.41$ $CaO=2.04$
$MgO=3.09$ Loss on ign.$=0.60$

33. Two Mica Granite.

Locality.—Prov. Mikawa. . (三河國額田郡瀧毛村). Medium grained; essentially composed of quartz, orthoclase, biotite and muscovite; notably fresh; orthoclase unaltered.

C. A:—

$Fe_2O_3 = 1.37$ $SiO_2 = 79.62$ $CaO = 0.93$

$Al_2O_3 = 15.53$ $MnO = 0.53$ Loss on ign $= 0.53$

34. Granite Porphyry.

Locality.—Prov. Omi. (近江國浦生郡沖ノ島). Distinctly porphyritic, light coloured phenocrysts of quartz and felspar embedded in greyish green coloured groundmass; essentially of quartz, orthoclase, and acid plagioclase; epidote and chlorite as secondary accessory constituents; phenocrysts are of quartz and felspar, their size ranging mostly between 10–20 mm; groundmass holocrystalline and composed essentially of granular aggregates of quartz and felspar, sparingly of epidote and chlorite; feldspar both of phenocryst and groundmass partly kaolinized.

C. A:—

$SiO_2 = 71.20$ $Fe_2O_3 = 1.54$ $CaO = 3.92$

$Al_2O_3 = 19.12$ $MgO = 0.91$ $MnO = 0.74$

35. Gneiss.

Locality.—Prov. Yamashiro. (山城國相樂郡笠置村). Fine grained (20–0.3 mm); schistose structure distinct; holes for the thermometers bored in the schistose plane, the direction connecting them lying in the same plane; essentially composed of quartz, orthoclase, biotite and muscovite.

C. A:—

$SiO_2 = 75.89$ $Fe_2O_3 = 1.20$ Loss on ign $= 0.64$

$Al_2O_3 = 13.86$ $MgO =$ trace $MnO = 0\ 57$

$CaO = 3.20$

36. Limestone.

Locality.—Prov. Chikuzen. (筑前國企數郡松ケ江村).

C. A:—

$Fe_2O_3 =$ trace $SiO_2 = 0.11$ $CaCO_3 = 99.93$

37. Oolitic Limestone.

Locality.—Prov. Musashi. (武藏國明治村). Light buff grey in colour and oolitic structure distinctly observed; bedding plane indiscernible; calcite vein with average thickness of 10 mm traverses the test piece parallel to one set of the cubical bounding planes, and the holes for the thermometers bored to parallel this vein running between them; flaws abundant; essentially of calcite; no foreign material, but coarse crystalline aggregate of calcite is present in the center of the oolites, which range in diameter between 2.5–0.3 mm, consisting of concentric layers of about 0.01 mm in thickness; matrix is of calcite 'showing honey-comb structure.

C. A:—

$SiO_2 = 1.84$ $Fe_2O_3 = 0.27$ $CaCO_3 = 94.98$

$Al_2O_3 = 3.79$

38. Ogasawara Limestone.

Locality.—Boniss Island. (小笠原島). Colour white with light pink tone; structure somewhat porous; texture very fine (often as fine as 0.01–0.005 mm), except the remains of foraminifera which are of coarse aggregates of calcite; essentially composed of fine granular calcite, and remarkably free from contaminations.

C. A:—
Fe_2O_3 = trace SiO_2 = 0.11 $CaCO_3$ = 99.93

39. Coral Limestone.

Locality.—Boniss Island. (小笠原島). Colour white; essentially of calcite; original structure of corals distinctly observed, cavities being still unfilled to a considerable extent, hence porous in structure, though not uniform throughout the test piece.

C. A:—
SiO_2 = 1.09 Fe_2O_3 = 0.88 MnO = trace
$CaCO_3$ = 97.43

40. Tanba Limestone.

Locality. Prov. Tanba. (丹波國). Dark grey coloured; compact and fine in texture; white coloured calcite veins of less fine texture and of 0.5–3.0 mm thickness traverse the test piece in various directions; essentially of calcite; size of individual grains ranging mostly between 0.1–0.01 mm except in vein portions, where crystals of 0.5 mm size are not rare; quartz and carbonaceous matter present as accessory ingredients.

C. A:—
SiO_2 = 23.08 Fe_2O_3 = 0.082 MnO = trace
Al_2O_3 = 0.18 $CaCO_3$ = 74.65

41. Limestone.

Locality.—Prov. Awa. (阿波國伊賀郡加茂村). A member of paleozoic group; colour light grey with white veins running in divers directions; very compact; no trace of bedding plane; essentially composed of calcite; texture very fine (0.01 mm) except in vein portions, where it is coarser (0.3–1.5 mm) and honeycomb structure is observed.

C. A:—
Al_2O_3 = 0.66 SiO_2 = 1.30 Fe_2O_3 = 1.00
$CaCO_3$ = 97.21

42. Arkose Sandstone.

Locality.—Prov. Mino. (美濃國). Light coloured, not very compact; no bedded structure observed; essentially composed of angular to subangular grains of quartz, orthoclase, perthite, plagioclase, and somewhat rounded fragments of clay-state; grains are mostly of 1–0.3 mm size; felspars are partly kaolinized.

C. A:—
Al_2O_3 = 12.98 CaO = 2.89 SiO_2 = 82.95
MnO = 0.23 Fe_2O_3 = 1.89

43. Limestone.

Locality. Prov. Kii. (紀伊國日高郡白野村). Structure is more or less brecciated; general course of bedding plane discernible; direction of conductivity measurement parallel to the bedding plane; colour light grey, showing veins of light green colour; essentially of calcite; of accessory constituents epidote and chlorite noteworthly; orthoclase and quartz also present; exhibit honey-comb structure, grains ranging between 5.0–0.01 mm; epidote, chlorite, feldspar and other accessories occur in veins generally parallel to one another.

C. A:—

$Al_2O_3 = 0.88$ $MnO = \text{trace}$ $SiO_2 = 5.76$

$CaCO_3 = 93.54$ $Fe_2O_3 = 0.50$

44. Chromite.

Locality.—Prov. Bitchu. (備中國阿哲郡).

C. A:—

$Al_2O_3 = 6.6$ $MgO = 10.39$ $SiO_2 = 3.12$

$Cr_2O_3 = 55.39$ $Fe_2O_3 = 21.56$

45. Dolomite.

Locality.—Prov. Buzen. (豐前國恒見地方). Light grey coloured; looks uniform and no bedded structure observed, except the presence of a few dark coloured veins; effervesces freely in cold dilute solution of HCl, and should properly be called "Magnesian Limestone"; crystalline and even grained (1.5–0.5 mm); abounds both in fine inter and intra-crystalline cracks, making the attempts to prepare sections impossible.

C. A:—

$Al_2O_3 = 1.35$ $CaCO_3 = 72.58$ $SiO_2 = 0.56$

$MgCO_3 = 22.13$ $Fe_2O_3 = 2.95$

46. Hornblende-Gabbro.

Locality.—Prov. Awadi. (淡路國津名郡鹽田村). Dark coloured; essentially of hornblende biotite, and basic plagioclase; quartz occur as accessory constituents in the interstices; apatite and magnetite also as accessorics; microstructure not typically gabbroid; medium grained (3–0.5 mm).

C. A:—

$Fe_2O_3 = 2.13$ $MnO = 0.48$ $SiO_2 = 51.84$

$FeO = 7.59$ $Al_2O_3 = 19.28$ $MgO = 7.55$

$CaO = 9.46$

47. Basalt.

Locality.—Prov. Tanba. (丹波國久夜久野村). Dark grey coloured; no vesicular cavities; essentially of basic plagioclase, augite, and olivine; magnetite as accessory constituent; olivine altered to iddingsite; nearly holocrystalline, glassy base being negligible in quantity; phenocrysts of plagioclase and olivine both of the order of 0.8 mm in size present very sparingly, while the groundmass is of lath shaped felspar and stout prismatic or equant crystalls of olivine and augite ranging in size between 0.4-0.15 mm; structure accordingly, not distinctly porphyritic.

C. A :—

$Fe_2O_3=1.00$ $MnO = 0.49$ $SiO_2=69.48$
$FeO =9.43$ $Al_2O_3=11.67$ $CaO= 5.00$
$MgO =2.47$

48. Owari Clay.

Locality.—Prov. Owari. (尾張國).

C. A :—

$Al_2O_3=40.81$ $CaO=0.72$ $SiO_2=57.67$
$Fe_2O_3=$trace

49. Hakata Clay.

Locality.—Prov. Chikuzen. (筑前國). This test piece was made of the Hakata clay burnd at the temperature about 800°*C.*

C. A :—

$Al_2O_3=24.19$ $MgO =$trace $SiO_2=73.70$
$CaO = 0.75$ $Fe_2O_3=$trace

50. Raw Clay.

Locality.—Prov. Chikuzen. (筑前國). Oven dried, powdered in motor and then pressed into the form.

C. A :—

$Al_2O_3=21.72$ $MgO =$trace $SiO_2=75.82$
$CaO = 0.59$ $Fe_2O_3=0.73$

51. Clay.

Locality.—Prov. Owari. (尾張國). The test piece is made of the powder of Kibushi clay mixed with water and pressing into the desired form.

C. A :—

$Al_2O_3=38.20$ $MgO =$trace $SiO_2=61.70$
$CaO = 1.09$ $Fe_2O_3=$trace

52. Clay.

Locality.—Prov. Iwaki. (盤城國石城郡).

C. A :—

$Al_2O_3=35.37$ $MgO =$trace $SiO_2=63.94$
$CaO = 0.42$ $Fe_2O_3=0.31$

53. Clay (1).

Locality.—Prov. Owari. (尾張國).

C. A :—

$Al_2O_3=24.08$ $CaO=0.56$ $SiO_2=75.79$
$Fe_2O_3=$trace

54. Tuff.

Locality.—Prov. Yamato. (大和國北葛城郡二上村). Light grey coloured; structure brecciated; plane of bedding indiscernible; angular fragments ranging in size between 20.0–0.5 mm loosely cemented by fine volcanic ash; fragments are mostly of mica bearing to pyroxene andesite with hyalopilitic groundmass, and of dominantly glassy andesite lava with garnet as accessory constituents; belongs to tertiary system.

C. A :—

SiO_2 = 73.77 Fe_2O_3 = 2.77 CaO = 2.53
Al_2O_3 = 15.34 MgO = 0.50 MnO = 0.21

55. Liparite-Tuff.

Locality.—Prov. Harima. (播磨國印南郡阿彌陀村). Buff coloured; clostic structure distinct, but no course of bedding plane observed; essentially of angular fragments of quartz, orthoclase, and also of fine textured groundmass of acid volcanic rock showing flow structure; matrix resembles the groundmass of the original volcanic rock both in composition and texture; some of the feldspars kaolinized; limonite present as accessory.

C. A :—

Fe_2O_3 = 2.75 MnO = 0.43 SiO_2 = 74.65
Al_2O_3 = 14.91 CaO = 1.53 MgO = trace

56. Liparite-Tuff.

Locality.—Prov. Bitchu. (備中國). Light pink colour; structure brecciated; no plane of bedding discernible; angular fragments of quartz, orthoclase, plagioclase of 1–0.2 mm size embedded in fine textured matrix, which is also substantially of fine particles (0.05–0.005 mm) of these minerals; belongs to tertiary system.

C. A :—

SiO_2 = 76.64 Fe_2O_3 = 2.75 CaO = 0.96
Al_2O_3 = 3.59 MgO = trace MnO = 0.20

57. Liparite-Tuff.

Locality.—Prov. Harima. (播磨國印南郡阿彌陀村). Coloured light grey with greenish tinges; no bedded structure obsesved; quartz, orthoclase, and plagioclase embedded in fine textured matrix; feldspar mostly altered to calcite, kaoline, and other hydrated aluminous silicate; belong to tertiary system.

C. A :—

SiO_2 = 75.53 Fe_2O_3 = 2.68 CaO = 1.23
Al_2O_3 = 13.81 MgO = trace MnO = 0.2

58. Tuff Breccia.

Locality.—Prov. Yamato. (大和國葛城郡二下村).

C. A :—

Fe_2O_3 = 2.10 MnO = 0.49 SiO_2 = 76.12
FeO = 1.01 Al_2O_3 = 14.72 CaO = 2.46
MgO = 0.36

59. Pumiceous Tuff.

Locality.—Prov. Ugo. (羽後國雄勝郡院內鑛山). Light buff coloured; structure brecciated; plane of bedding observed; fragments smaller both in size (1.00 mm less) and number than in the forgoing specimen; microscopically rounded to subangular fragments of quartz plagioclase, augite, and hypersthene observed as essential constituents; fragments of two-pyroxene andesite with hyalopilitic grounsmass also common; fragments of pumice very abundant and its fine powder prevalent in the matrix; belongs to tertiary system.

C. A:—

$SiO_2 = 73.60$ $Fe_2O_3 = 2.84$ $CaO = 2.35$

$Al_2O_3 = 15.34$ $MgO = 0.84$ $MnO = 0.21$

60. Schalstein.

Locality.—Prov. Iwaki. (岩城國伊達郡飯坂町). Tertiary system.

C. A:—

$Fe_2O_3 = 0.80$ $Al_2O_3 = 12.70$ $SiO_2 = 71.86$

$FeO = 0.20$ Loss on ign $= 10.61$ $CaO = 2.41$

$MgO = 0.42$

61. Marl.

Locality.—Prov. Musashi. (武藏國西多摩郡舘谷村). Light brownish grey coloured dolomitic marl; a member of tertiary system; plane of bedding distinct; holes for the thermometers bored parallel to the bedding plane, the direction connecting them running perpendicular to it; essentially composed of fine (0.05–0.005 mm) granular calcite and dolomite; fine grains of quartz, clayey substance, limonite, and iron-pyrite accessories present; remains of foraminifera abundant; they range in size between 1.0–0.03 mm, and are usually of coaser aggregates of calcite.

C. A:—

$Fe_2O_3 = 1.53$ $CaCO_3 = 45.27$ $SiO_2 = 14.14$

$MgCO_3 = 34.27$ $Al_2O_3 = 1.19$ $Fe_2O_3 = 2.48$

$MnO = 0.58$

62. Siliceous sinter.

Locality.—Prov. Kaga. (加賀國江沼郡山中村). Recent deposit; white coloured hyalite globules of 4–1 mm in diameter partly cemented with considerable inter-globular space unfilled, hence porous in structure; both globules and cement are of opaline silica.

C. A:—

$SiO_2 = 95.16$ $Fe_2O_3 = 0.70$ Loss on ign. $= 4.50$

63. Idzumi sand-stone.

Locality.—Prov. Awa. (阿波國板野郡大津村). Grey coloured sandstone of cretaceous system; uniform in structure and no plane of bedding discernible; composed of angular grains of quartz, orthoclase, plagioclase, fragment of quartzite and slate; clayey substance and chlorite also present muscovite, calcite, and leucoxene sparingly present as accessory constituents; grains mostly of 0.5 mm size.

C. A:—

$Fe_2O_3 = 0.47$ $MnO = 0.40$ $SiO_2 = 76.37$

$FeO = 4.56$ $Al_2O_3 = 12.53$ $CaO = 1.82$

$MgO = 1.90$

64. Hornblende Gabbro.

Locality.—Prov. Chikuzen. (筑前國糟屋郡志賀島). Dark green in colour; coarse textured; essentially of hornblende, augite, plagioclase, orthoclase, and microcline; pyrite, magnetite, and apatite as accessory components; hornblende is of light brown variety partly altering to light green one and stout prismatic or nearly equant in habit, ranging diameter between 8–2 mm; augite is of diopside series and smaller both in size (0.3–0.1 mm) and quantity; felspars which are partly saussuritized play the role of matrices toward idiomorphic crystals of hornblende and augite.

C. A :—

$Fe_2O_3 = 4.37$ $MnO = 0.67$ $SiO_2 = 55.46$
$FeO = 5.14$ $Al_2O_3 = 10.33$ $CaO = 12.63$
$MgO = 10.39$

65. Rhyolite.

Locality.—Prov. Mino. (美濃國). Light coloured and distinctly porphyritic; phenocrysts are of quartz, orthoclase, and acid plagioclase, ranging in size between 2.0–0.3 mm; epidote occurs as pseudomorphs after hornblende which formerly played the role phenocryst; groundmass which was originally hyaline and spherulitic has been devitrified and now consists of crystalline granuler aggregates of quartz and felspar (0.08–0.01 mm in size).

C. A :—

$Fe_2O_3 = 1.63$ $SiO_2 = 79.60$ $MgO = 0.23$
$MnO = 0.40$ $CaO = 3.80$ $FeO = 0.57$
Loss on ign. = 1.52

66. Serpentine.

Locality.—Prov. Hitachi. (常陸國久慈郡町屋町). Alteration product of peridotite; variegated in dark green or almost black and light green; texture very compact; essentially composed of serpentine, tremolite, talc and olivin, the former two predominating by far the latter two; magnetite occurs as accessory constituents; serpentine shows mesh structure, while tremolite occurs sporadically forming radical aggregates.

C. A :—

$Fe_2O_3 = 5.71$ $SiO_2 = 43.72$ $MgO = 34.17$
$Al_2O_3 = 4.24$ $CaO = 4.03$ $FeO = 1.33$
Loss on ign. = 7.46

67. Diorite.

Locality.—Prov. Tanba. (丹波國天田郡). Light in colour, coarse grained and somewhat porphyritic; 2–5 mm sized idiomorphic hornblende in hypidiomorphic to xenomorphic granular aggregates of felspar, quartz, biotite, and hornblende, which are mostly 0.3–0.1 mm in size; especially those of the groundmass, are remarkably saussuritized; hornblende and biotite partly chloritized; ilmenite, epidote, and leucoxens as accessory components.

C. A :—

$Fe_2O_3 = 5.93$ $MnO = 0.56$ $SiO_2 = 54.34$
$FeO = 3.81$ $Al_2O_3 = 21.47$ $CaO = 7.86$
$MgO = 4.64$

68. Sandstone.

Locality.—Prov. Kawachi. (河內國勝浦郡高鉾村). Dark coloured, fine and compact in texture; no bedded structure; hollow cast of trigonia seen on one of the edges of the test piece; essentially composed of anguler grains of quartz, felspar, and biotite, size of grains ranging between 0.2–0.1 mm; fragments of clayed rock, chlorite, muscovite, epidote, and coaly substance present as accessory ingredients; felspar partly kaolinized.

C. A:—

$Fe_2O_3=5.76$ $SiO_2=68.6$ $MgO=$ trace
$MnO=0.54$ $Al_2O_3=19.54$ $CaO=1.84$
Loss on ign $=2.72$

69. Augite Porphyrite.

Locality.—Prov. Kai. (甲斐國北都留郡). $FeO=3.80$. Light grey coloured; holocrystalline, porphyritic tending to even grained texture; essentially composed of plagiaclase and augite (1.5–0.3 mm in size); hornblende and magnetite occur as accessory components; chlorite present as alteration product probably of biotite.

C. A:—

$Fe_2O_3=2.84$ $SiO_2=54.86$ $MgO=2.71$
$MnO=0.80$ $Al_2O_3=23.96$ $CaO=9.47$
$FeO=3.80$ Loss on ign $=0.75$

70. Pearlite.

Locality.—Prov. Mikawa. (三河國設樂郡鳳來寺山). Light greenish grey in colour; nearly holohyaline; crystals of quartz, sanidine, and biotite of 2–0.5 mm size, not exceeding 5% in volume present as phenocrysts; pearlitic cracks as well as somewhat larger cracks abundant; slight devitrification observed along these cracks.

C. A:—

$Fe_2O_3=0.62$ $SiO_2=69.92$ $CaO=4.12$
$FeO=1.14$ $Al_2O_3=15.87$ Loss on ign. $=7.88$

71. Rhyolite.

Locality.—Prov. Etchū. (越中國上新川郡立山村). Dark grey coloured and very compact in texture; distinctly porphyritic; phenocrysts are mostly of orthoclase; groundmass devitrified; effect of silicification distinct; fine veins of quartz and of epidote present; magnetite, pyrite, and chlorite present as accessory constituents.

C. A:—

$SiO_2=72.27$ $Fe_2O_3=5.52$ $MnO=0.30$
$Al_2O_3=11.34$ $CaO=3.32$ $FeO=3.26$

72. Porphyrite.

Locality.—Prov. Higo. (肥後國). Grey coloured and finely spotted with dark and white; essentially of basic plagioclase, augite, and hypersthene; magnesite as accessory constituents; aggregates of fine grained magnetite and augite showing somewhat indistinct outline of prismatic crystal observed, probably results of complete resorption of hornblende; component mineral range in size mostly between 1.0–0.3 mm, and the structure tends more to panidiomorphic than to porphyritic.

C. A:—

SiO_2 = 57.12 Fe_2O_3 = 1.48 MgO = 4.42
Al_2O_3 = 23.26 CaO = 8.54 FeO = 4.00

73. Porphyrite.

Locality. Prov. Ōmi. (近江國坂田郡伊吹山). Colour almost uniformly green due to alteration; texture fine and porphyritic to even grained; felspar is the only original essential constituent that remains unaltered; of secondary constituents; chlorite and epidote are essential, calcite and pyrite being accessory.

C. A:—

Fe_2O_3 = 9.03 SiO_2 = 55.90 MgO = trace
MnO = 0.74 Al_2O_3 = 23.51 CaO = 7.54
Loss on ign. = 2.47

74. Porphyrite.

Locality.—Prov. Bitchū. (備中國川上郡成羽村). Colour uniformly dark green; texture holocrystalline, porphyrite; phenocrysts are of andesite and augite and 2–0.8 mm in size; groundmass is also of andesite and augite tending to intersertal in structure, size of crystals ranging mostly between 0.2–0.05 mm; chlorite, epidote, calcite and magnetite important as accessory constituents.

C. A:—

SiO_2 = 57.30 Fe_2O_3 = 10.05 Loss on ign. = 2.03
Al_2O_3 = 20.55 CaO = 8.00 MnO = 0.54

75. Gritty Limestone.

Locality.—Prov. Boniss Island. (小笠原島). Light grey coloured; compact and homogeneous with no trace of bedding plane; essentially composed of fine grained calcite and angular fragments (0.3–0.1 mm in size) of acid plagioclase, the former playing the role of cementing material; augite, hypersthene, hornblende, magnetite, and subangular or rounded grains of glassy to hypocrystalline groundmass of volcanic rocks also present; fragments of fossil lamellibranchs and other mollusks abundant.

C. A:—

SiO_2 = 30.92 Fe_2O_3 = 3.54 $CaCO_3$ = 53.96
Al_2O_3 = 9.58 MnO = 0.23 FeO = 1.33

76. Gneiss,

Locality.—Prov. Shinano. (信濃國). Dark coloured, medium grained (4–0.5 mm); shistose structure distinct; direction of conductivity measurement paralled to the schistose plane; essentially of quartz, orthoclase, oligoclase, hornblende, and biotite; strain shadows observed in quartz; apatite, zircon, and epidote as accessory constituents.

C. A:—

Fe_2O_3 = 3.45 SiO_2 = 65.90 MgO = 0.58
MnO = 1.34 CaO = 5.50 FeO = 3.81
Al_2O_3 = 17.30 Loss on ign. = 0.65

77. Volcanic Scoria.

Locality.—Prov. Satsuma. (薩摩國櫻島). Dark brown coloured and highly vesicular; cavities range in diameters between 0.05–10 mm, and exceed 60% in aggregate volume; texture hypocrytalline porphyritic; phenocrysts are of plagioclase, augite, and hypersthene; groundmass is dominantly of brown coloured glass; microlites are of acicular crystals of felspar and pyroxene; magnetite present as accessory constituents.

C. A :—

$SiO_2 = 65.70$ $Fe_2O_3 = 7.78$ Loss on ign. = 0.72
$Al_2O_3 = 19.00$ $CaO = 4.39$ $MnO = 2.59$

78. Shale.

The specimen was lost after the determination of thermal properties and chemical composition, making the petrological observation impossible.

C. A :—

$Fe_2O_3 = 11.66$ $SiO_2 = 64.18$ MgO = trace
MnO = trace $Al_2O_3 = 15.21$ $CaO = 6.58$

79. Olivin Andesite.

Locality.—Prov. Idzu. (伊豆國三島一町町). Dark grey coloured and vesicular in structure; distinctly porphyritic, phenocrysts being dominantly of plagioclase; groundmass in nearly holocrystalline, tending from intersertal to ophitic in structure, and composed essentially of plagioclase, augite, olivine, magnetite, and a little glassy base; phenocrysts of felspar range in size mostly between 5–1 mm; olivine sometimes reaches 0.8–0.4 mm in size and plays the role of phenocryst.

C. A :—

$Fe_2O_3 = 4.88$ MnO = trace $SiO_2 = 53.84$
$FeO = 7.24$ $Al_2O_3 = 18.54$ $CaO = 9.49$
$MgO = 5.86$ $CuO = 0.016$

80. Sanukite.

Locality.—Prov. Yamato. (大和國北葛城郡二上村). Colour blak; dense and very fine in texture; essentially composed of dark brown glass and microlites of bronzite and plagioclase, mostly of 0.03–0.01 mm in size; phenocrysts typically absent.

C. A :—

$Fe_2O_3 = 2.12$ $MnO = 0.42$ $SiO_2 = 63.65$
$FeO = 5.61$ $Al_2O_3 = 17.96$ $CaO = 5.92$
$MgO = 1.84$

81. Amphibolite.

Colour dark green; schistosity indistinct; essentially composed of actinolite and chlorite; hematite, magnetite, titanite, and apatite as accessory constituents; the fibrous variety of actinolite,plays the role of matrix in which actinolite crystals (mostly of 2–1 mm in length) occur embedded, and often seen terminally transformed into fibrous variety.

C. A :—

$Fe_2O_3 = 14.27$ $MnO = 0.35$ $SiO_2 = 47.37$
$FeO = 7.22$ $Al_2O_3 = 2.88$ $CaO = 11.83$
$MgO = 13\ 64$

82. Porphyrite.

Locality.—Prov. Tanba. (丹波國南桑田郡保津村). Greyish green with dark green spots, dense in structure; porphyritic as well as other original textures somewhat obliterated due to alteration; phenocrysts are of plagioclase and hornblende and 1–3 mm in size; groundmass is holocrystalline and of the same minerals of 0.2–0 4 mm in size; essentially composed of plagioclase and hornblende; the former is mostly saussuritized, while the latter is chloritized; ilmenite occur as original accessory component; quartz, chlorite, epidote, calcite and leucoxene as secondary accessory components.

C. A :—

$Fe_2O_3 = 2.20$ $MnO = 0.74$ $SiO_2 = 67.14$
$FeO = 2.95$ $Al_2O_3 = 20.77$ $CaO = 3.80$
$MgO = 0.25$

83. Piedmontite-Schist.

Locality.—Prov. Awa. (阿波國名東郡大瀧山). Colour reddish grey; schistose structure distinct; test piece has been cut with the schistose plane running parallel to one set of the cubical bounding planes; direction of conductivity measurement parallel to the schistose plane; composed dominantly of quartz; subsidiarily of sericite and piedmontite; dematite, epidote, and apacite as minor accessory constituents.

84. Epidote-Schist.

Locality.—Prov. Awa. (阿波國名東郡). Greyish green with light yellowish tinge; structure banded, but schistosity not very distinct; notably dense; test piece has been cut with the plane of banding running parallel to one set of the cubical bounding planes; direction of conductivity measurement perpendicular to the plane of banding; essentially composed of epidote, chlorite, quartz and felspar; calcite and tourmaline as accessory constituents.

C. A :—

$SiO_2 = 47.16$ $MgO = 1\ 29$ $MnO = 0.53$
$Al_2O_3 = 24.08$ $CaO = 12.40$ $FeO = 2.79$
$Fe_2O_3 = 7.32$ Loss on ign. = 2.64 CuO = trace

85. Talc-Schist.

Locality.—Prov. Awa. (阿波國名東郡八萬村). Colour dark green; schistose structure distinct; finely laminated; direction of conductivity measurement nearly parallel to the schistose plane; essentially composed of actinolite, chlorite, talc, epidote, calcite, and felspathic minerals.

86. Muscovite.

Locality.—India. Sheet of the material, each 60×60×3 mm, are folded to the thickness of 60 mm, thus forming the test piece and the heat-flow paralled to the sheet.

87. Mica Powder.

Locality.—Prov. India. The test piece is made of mica powder prepared for casting mould.

C. A:—

SiO_2 =59.45 Fe_2O_3= 1.83 CaO =0.96
Al_2O_3=16.24 MgO =20.52 MnO=0.13

88. Asbestos.

The fibrous asbestos is pressed in a box of wood, thus making the test piece.

89. Brecciated Lava.

Locality.—Prov. Higo. (肥後國阿蘇山). Dark coloured and brecciated in structure; not very compact; essentially composed of glasssy andesitic lava with fragments of andesite more crystalline in texture; both are essentially of plagioclase, augite, hypersthene, and glassy base; andesitic lava is heterogeneous both in composition and texture, irregular lenticular masses of pitch black (dark brown in thin section) glass interlaminating with grey coloured hypocrystalline portions.

C. A:—

SiO_2 =62.18 Fe_2O_3=8.04 CaO=8.04
Al_2O_3 =19.94 MgO =trace Loss on ign.=1.45

90. Pyroxene Andesite.

Locality.—Prov. Satsuma. (摩國櫻島横山). Colour black, vesicular in structure, size of cavities ranging mostly between 0.2–4 mm, and exceeding 30% in aggregate volume; texture hypocrystalline porphyritic; phenocrysts are of plagioclase, augite, and hypersthene; felspar abounds in glassy inclosures; groundmass composed of brown coloured glass and microlites (0.02 mm in length) of felspar and pyroxene; magnetite present as accessory constituents.

C. A:—

Fe_2O_3=11.44 SiO_2 =56.68 MgO =trace
MnO = 0.73 Al_2O_3=21 40 CaO =9.38

91. Ash.

The ash, which is prepared by burning the straw, is put in a cubical box of wood.

92. Ash.

The ash of bone is put in a cubical box of wood.

93. Loam.

Locality.—Manchuria, China.

C. A :—

$Al_2O_3 = 19.42$ $CaO = 2.71$ $SiO_2 = 76.85$
$Fe_2O_3 = 0.49$ $MgO = 0.25$

94. Powder of Kaolin.

White powder of kaolin is also put in a box of wood.

95. Lime Powder.

The test piece is made of the powder of lime contained in a cubical box of wood.

96. White Porcelain.

The test piece is made of the material for making the Japanese table-ware.

C. A :—

$SiO_2 = 72.49$ $Fe_2O_3 = 3.66$ $CaO = \text{trace}$
$Al_2O_3 = 22.03$ $MgO = 0.24$

97. Brown Porcelain.

The test piece is made of the material commonly used for making the bottle.

98. Cement.

C. A :—

$Fe_2O_3 = 0.30$ $SiO_2 = 57.19$ $MgO = 0.79$
$MnO = 0.80$ $Al_2O_3 = 13.12$ $CaO = 19.03$
Loss on ign = 7.72

99. Soil.

Common dark soil is measured in a box of wood.

100. Soil used for casting.

Locality.—Prov. Chikuzen. (筑前國).

C. A :—

$SiO_2 = 75.31$ $Fe_2O_3 = 0.40$ $Al_2O_3 = 22.02$
$CaO = 2.17$

101. Slag (open hearth furnace).

The test piece is prepared from slag discharged from open-hearth furnace of the Imperial Steel Works.

C. A :—
$SiO_2 = 54.01$ $Fe_2O_3 = 15.65$ $CaO = 5.56$
$Al_2O_3 = 3.82$ $MgO = 0.49$ $MnO = 19.74$

102. Electric Furnace Slag.

The test piece is cut from slag discharged from arc-alloy of Imperial Steel Works.

C. A :—
$SiO_2 = 28.2$ $Fe_2O_3 = 1.58$ $CaO = 0.85$
$Al_2O_3 = 34.63$ $MgO = 3.30$ $Cr_2O_3 = 1.64$

103. Graphite Powder.

The test piece is made of the mixture of oil with the powder of graphite and pressed into the form.

C. A :—
Ash = 77.31 P = 0.019 Total sulphur = 0.01
C = 14.21

104. Carbon Rod.

The test piece is made of the carbon rod for the pole of arc-furnace.

C. A :—
C = 92.71 Total sulphur = 0.497 P in ash = 0.077
ash = 7.13

105. Charcoal Powder.

The test piece is made of the charcoal powder mixed with the oil and pressed into the desired form.

C. A —
Non-volatile = 37.93 Ash = 52.67 C = 33.64
Moisture = 3.31 Total sulphur = trace $H_2 = 0.93$
Volatile = 6.09 P in ash = 0.038 $O_2 = 12.31$
$N_2 = 0.45$

106. Coke Powder.

The test piece is made of the coke powder prepared for blast furnace of Imperial Steel Works, the coal being one to be given in Prov. Chikuzen.

C. A :—
Non-volatile matter = 44.35 total sulphur = 0.353 C = 41.7
Moisture = 1.1 P in Ash = 0.077 $H_2 = 0.65$
Volatile matter = 6.22 ash = 48.33 $O_2 = 8.567$
$N_2 = 0.4$

107. Coal.

Locality.—Prov. Chikuzen. The test piece is pressed into the form, from the powder of the raw coal.

C. A :—

Non-volatile = 34.39
Moisture = 1.58
Volatile = 26.5

Total sulphure = 0.138
P in ash = trace
Ash = 37.34

C = 41.34
H_2 = 3.32
O_2 = 16.66
N_2 = 1.01

108. Glass.

Transparent, but with a little blue colour.

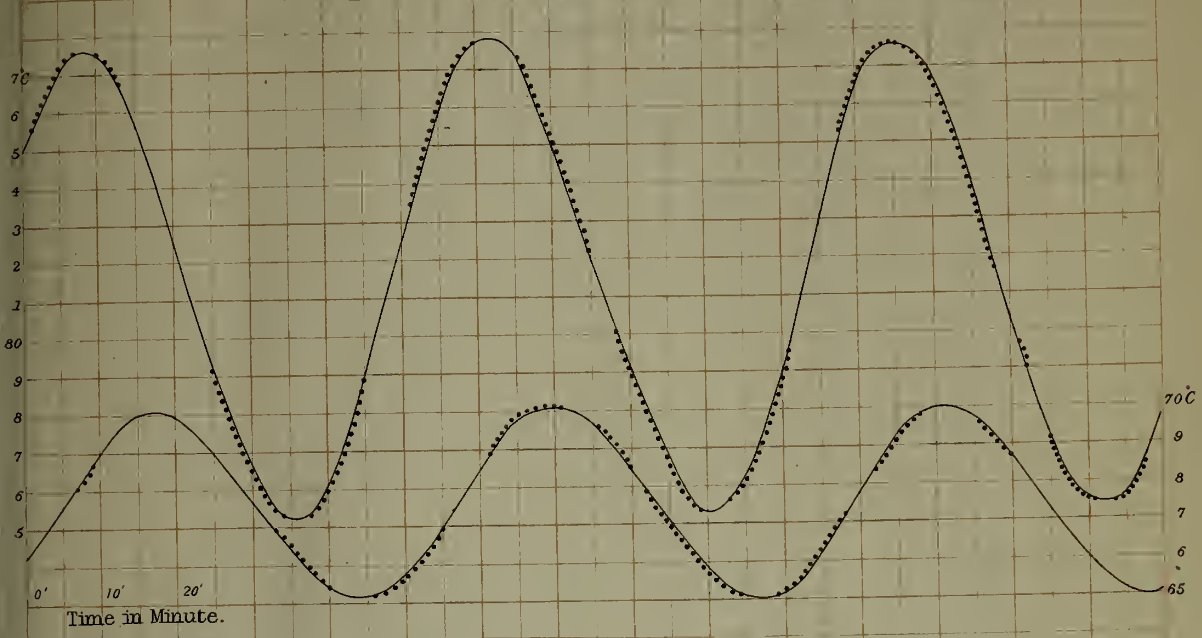
109. Cotton (Refined).

The test piece of cotton refined is measured also in a box of wood.

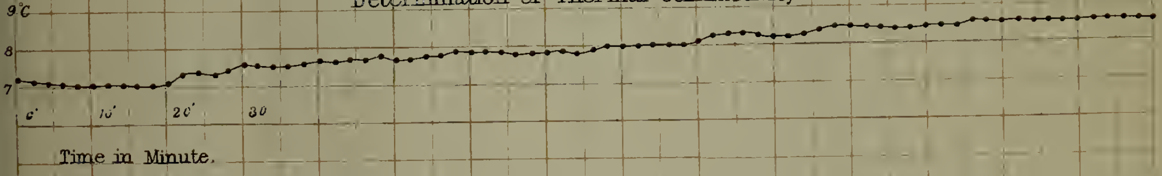
Pl. I.

Fig. 7. Chrome Brick.

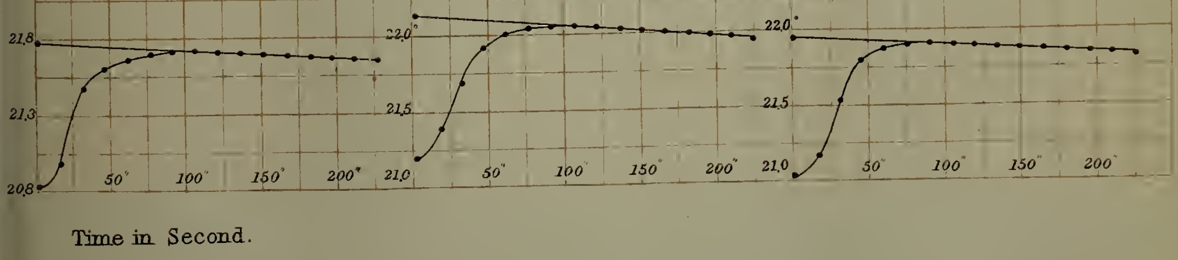
Temperature-time Curve for the Determination of Diffusibility.



Temperature-time Curve for the Determination of Thermal Conductivity.



Cooling Curve for the Determination of Specific Heat.



Pl. II.

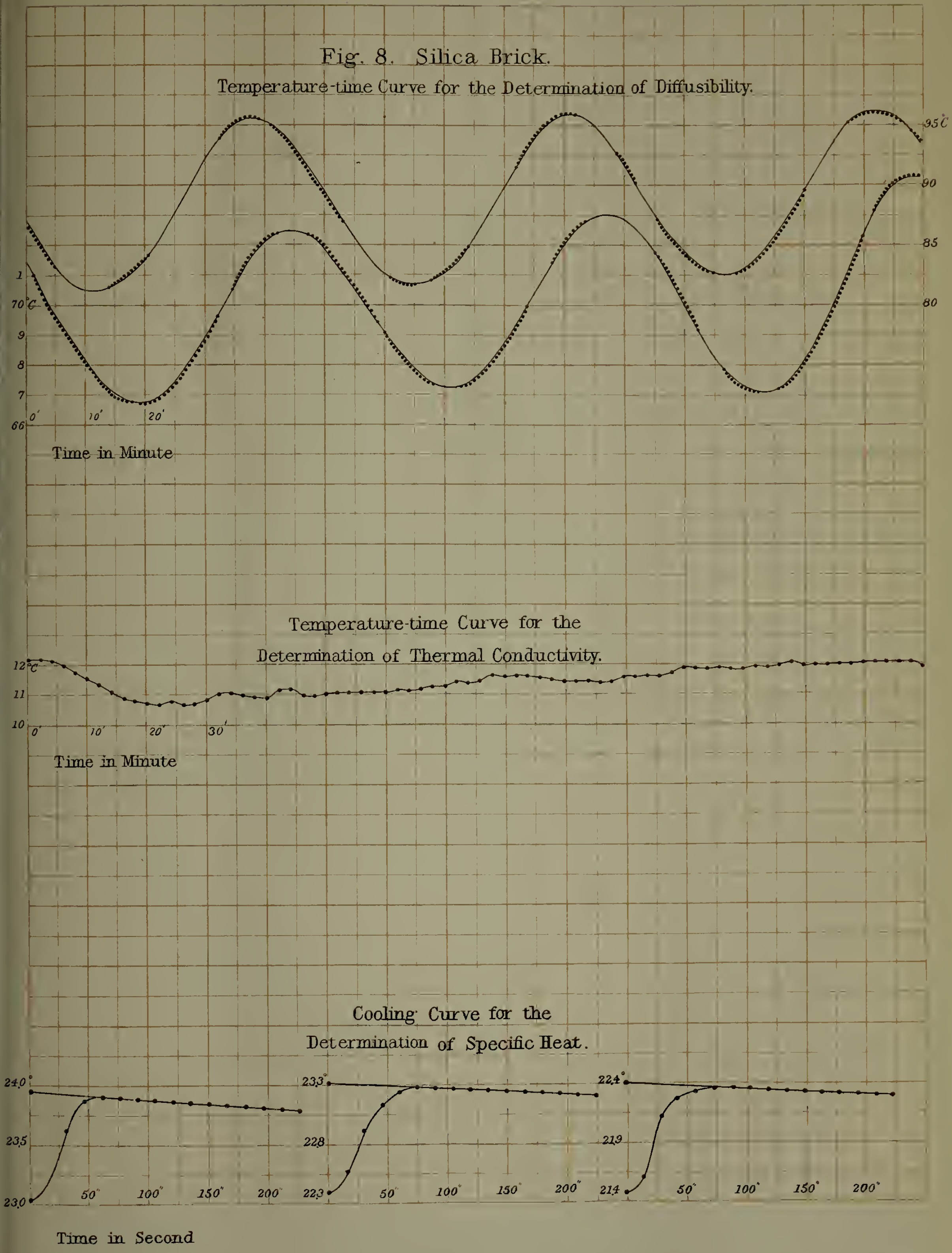


Fig. 8. Silica Brick.

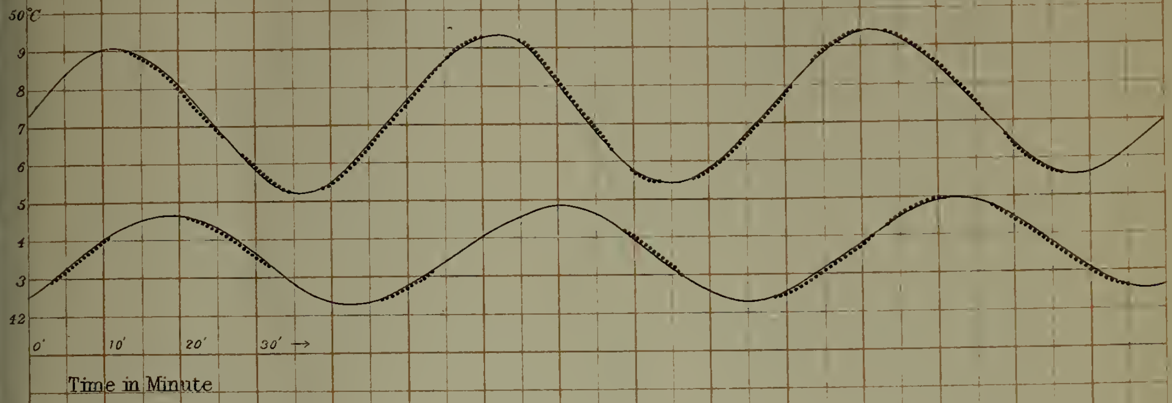
Temperature-time Curve for the Determination of Diffusibility.

Temperature-time Curve for the Determination of Thermal Conductivity.

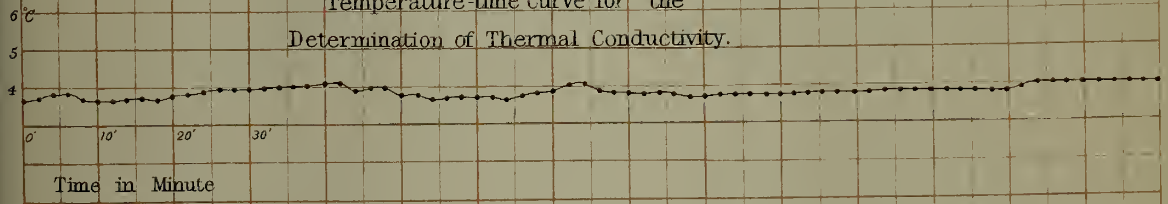
Cooling Curve for the Determination of Specific Heat.

Fig. 9. Magnesia Brick.

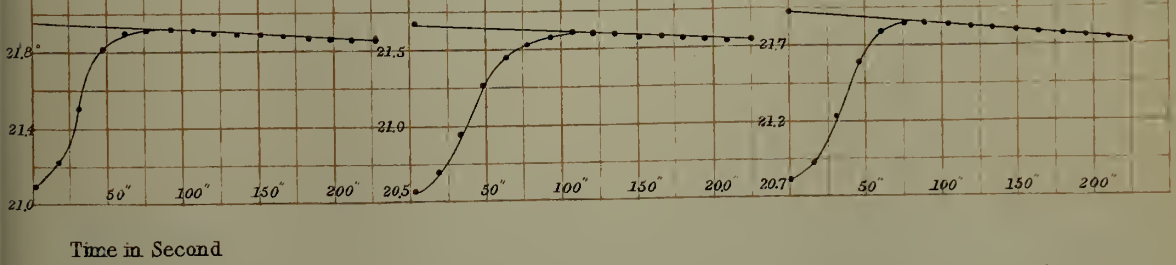
Temperature-time Curve for the Determination of Diffusibility.



Temperature-time Curve for the Determination of Thermal Conductivity.



Cooling Curve for the Determination of Specific Heat.



Pl. IV.

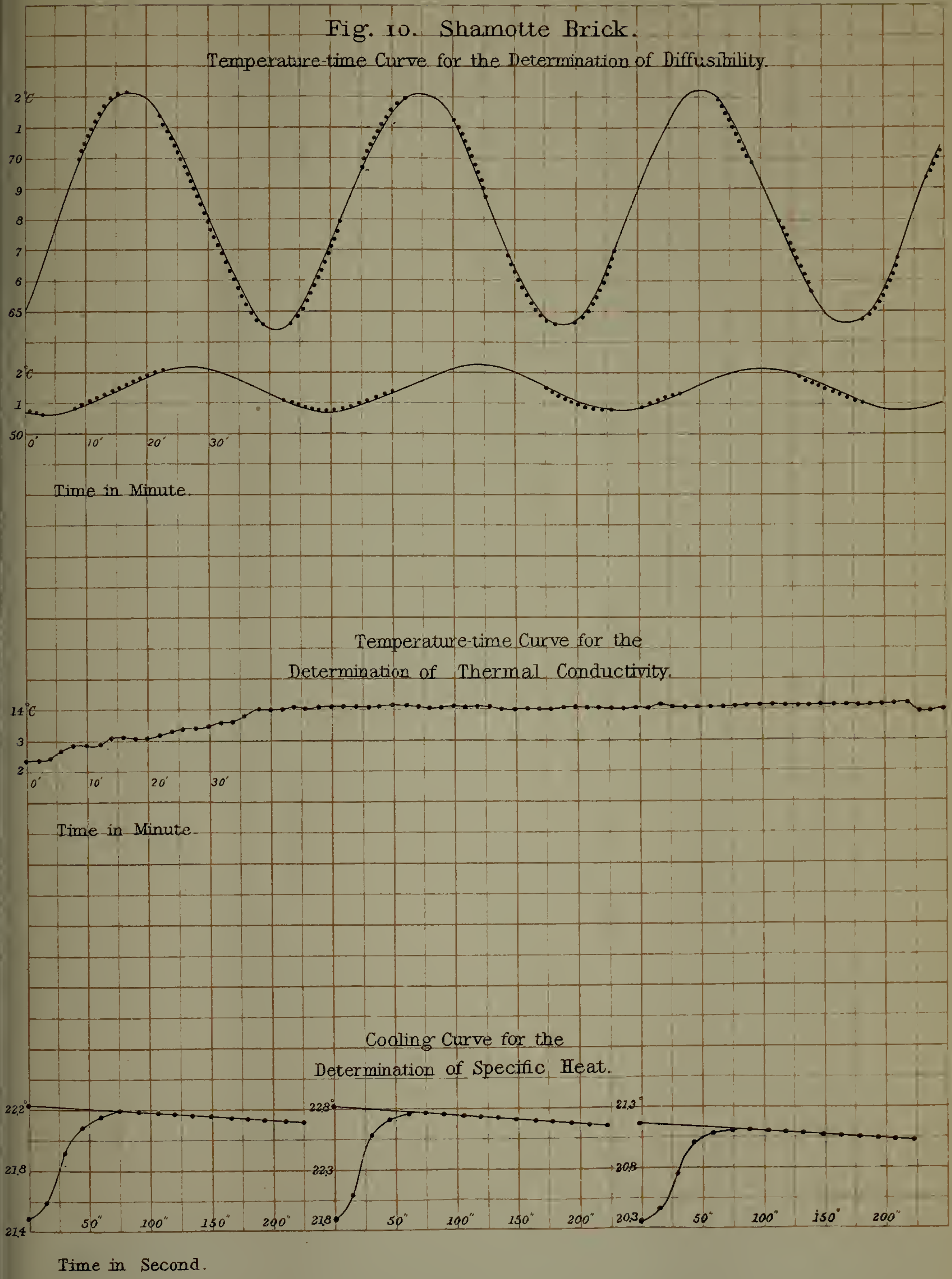


Fig. 10. Shamotte Brick.

Temperature-time Curve for the Determination of Diffusibility.

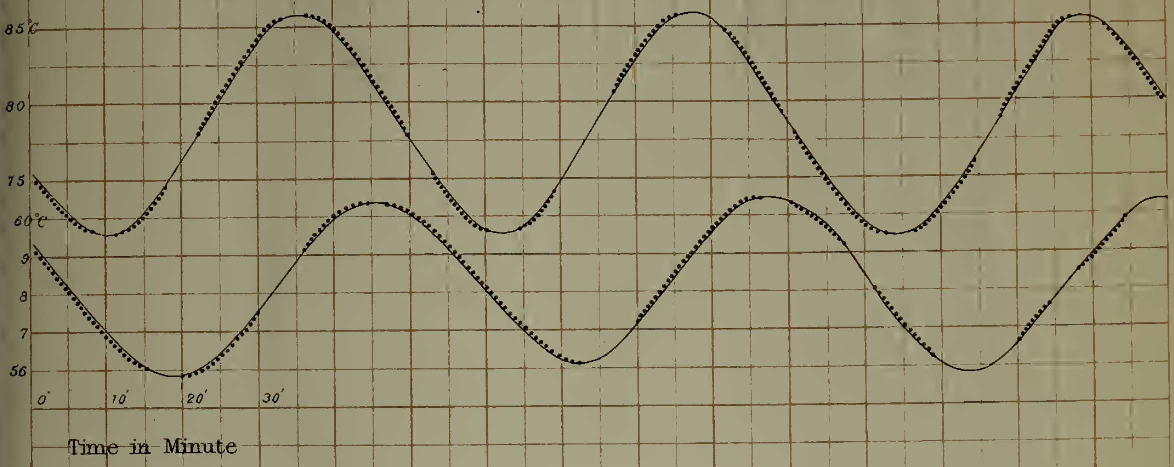
Temperature-time Curve for the Determination of Thermal Conductivity.

Cooling Curve for the Determination of Specific Heat.

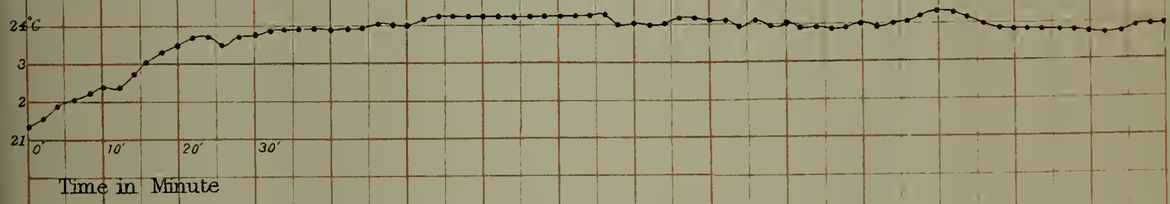
Pl. V.

Fig. 11. Common Red Brick.

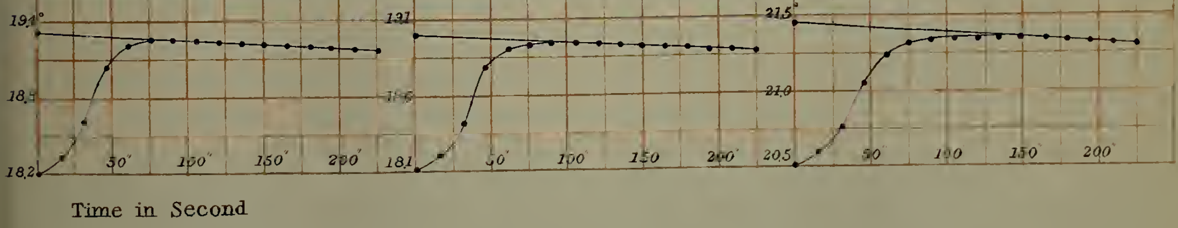
Temperature-time Curve for the Determination of Diffusibility.



Temperature-time Curve for the Determination of Thermal Conductivity.



Cooling Curve for the Determination of Specific Heat.



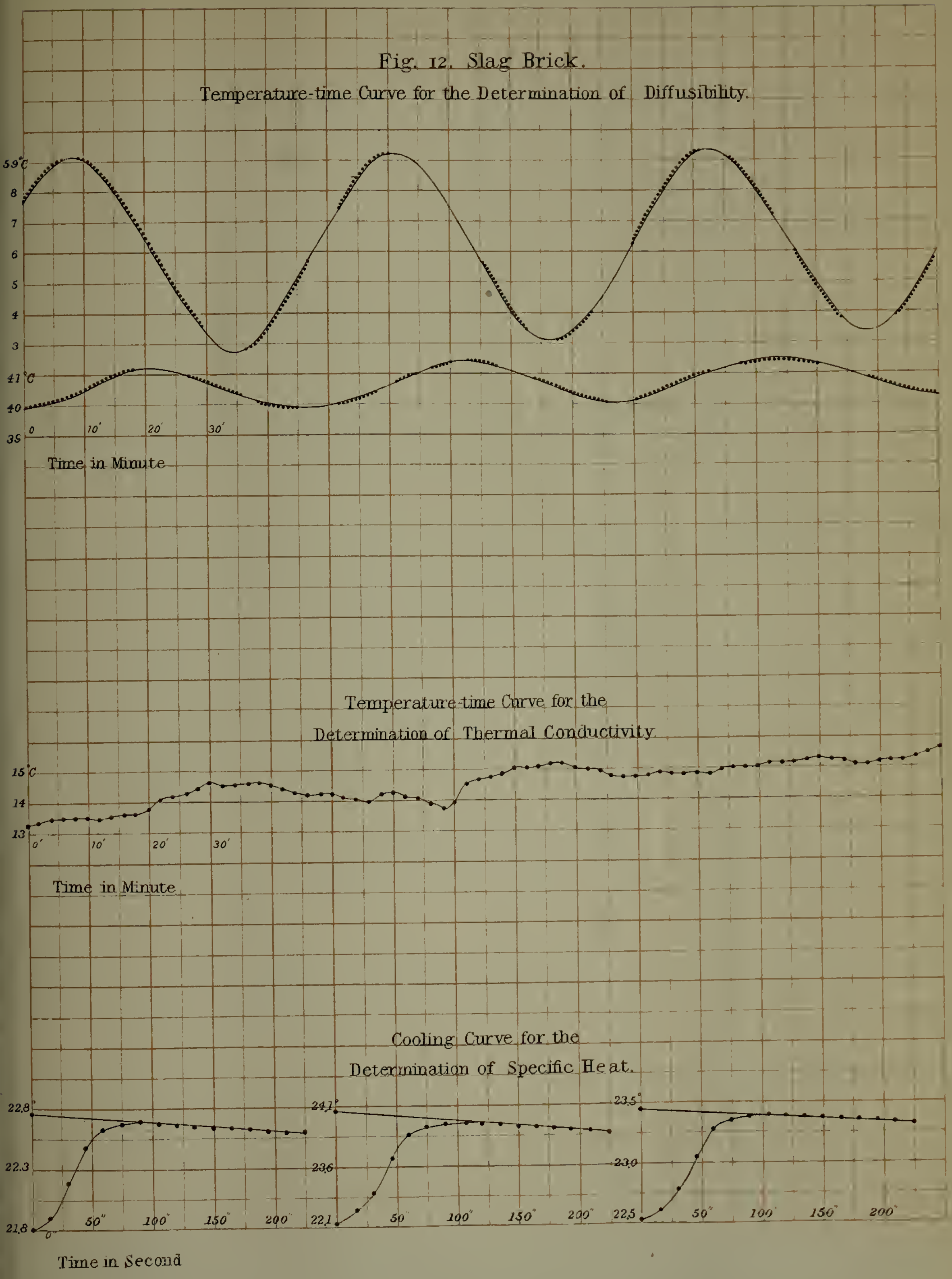


Fig. 12. Slag Brick.

Temperature-time Curve for the Determination of Diffusibility.

Temperature-time Curve for the Determination of Thermal Conductivity.

Cooling Curve for the Determination of Specific Heat.

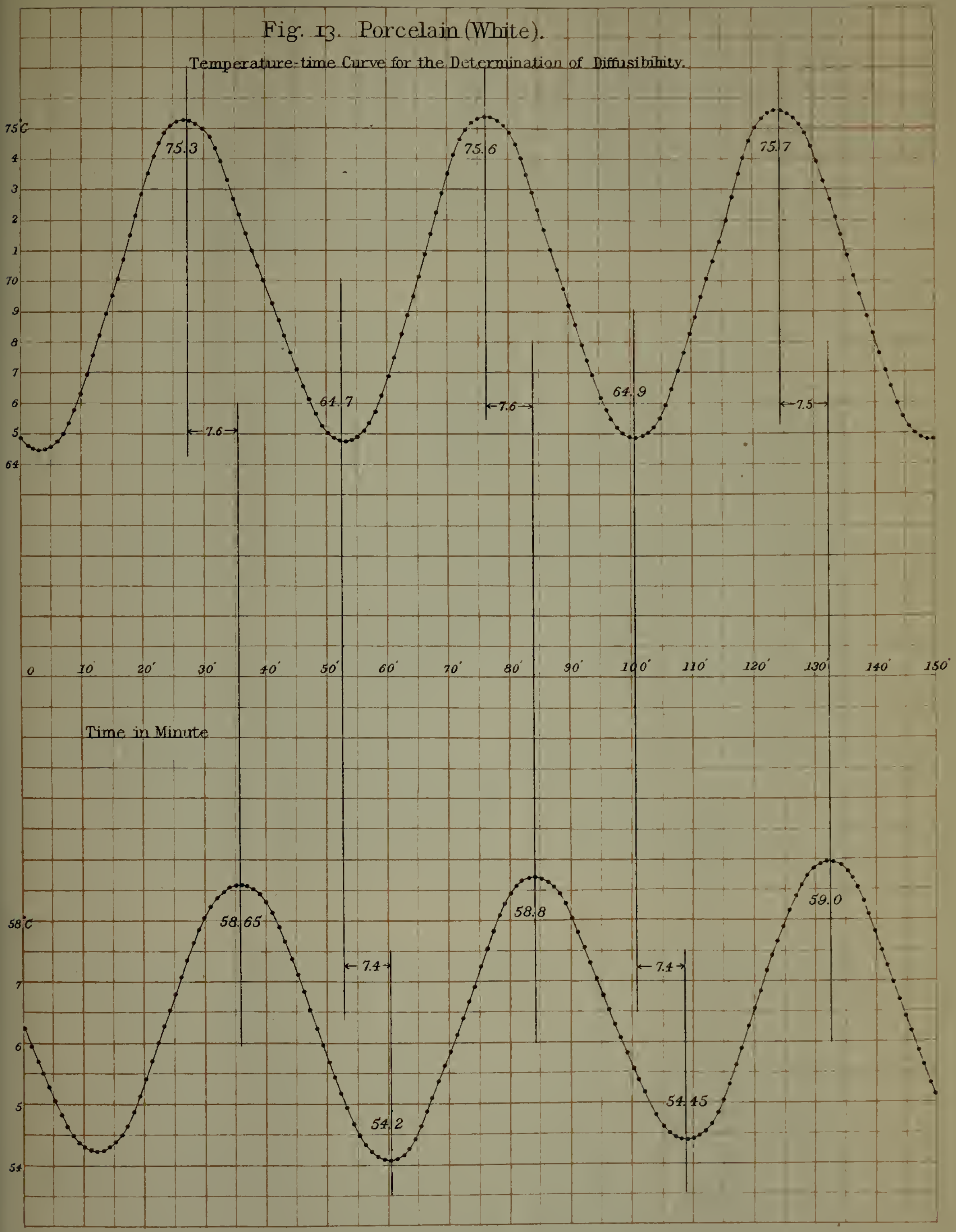


Fig. 13. Porcelain (White).

Temperature-time Curve for the Determination of Diffusibility.

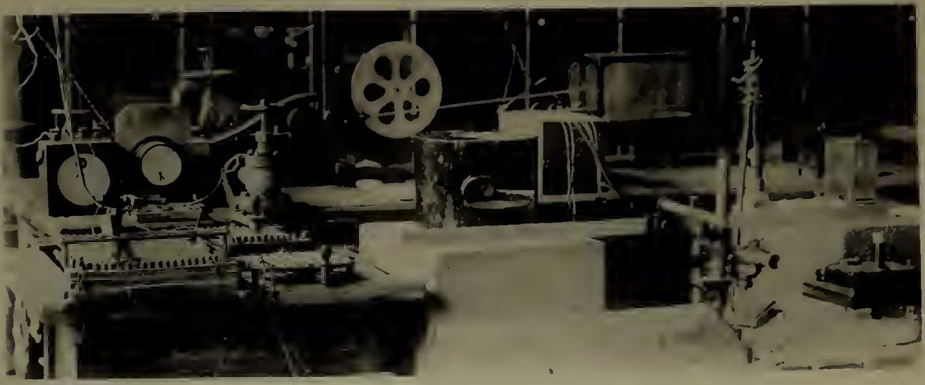


Fig. 6.

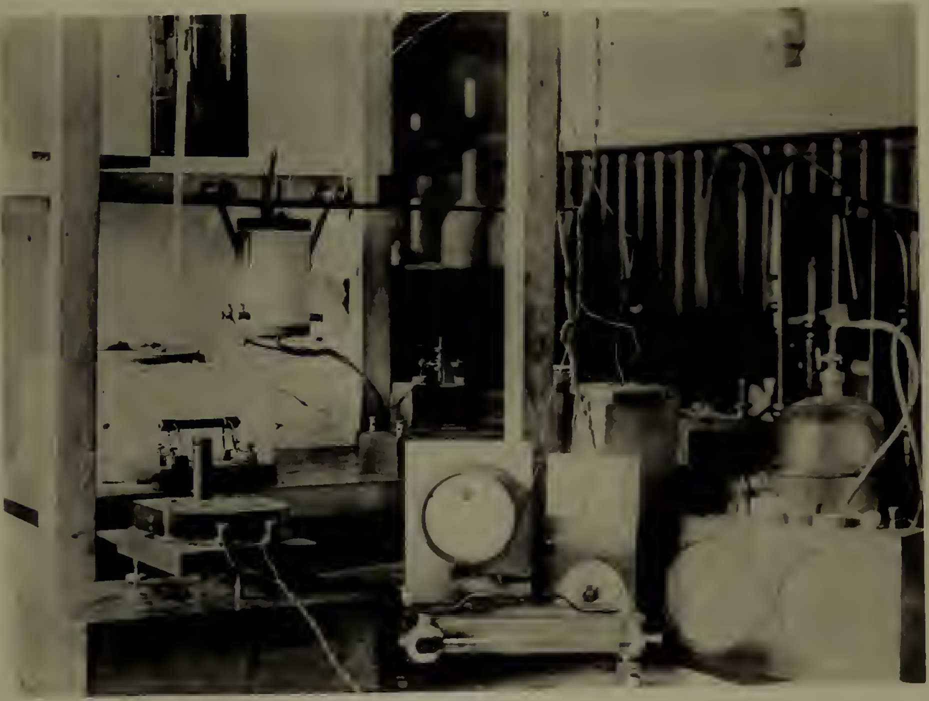


Fig. 14.

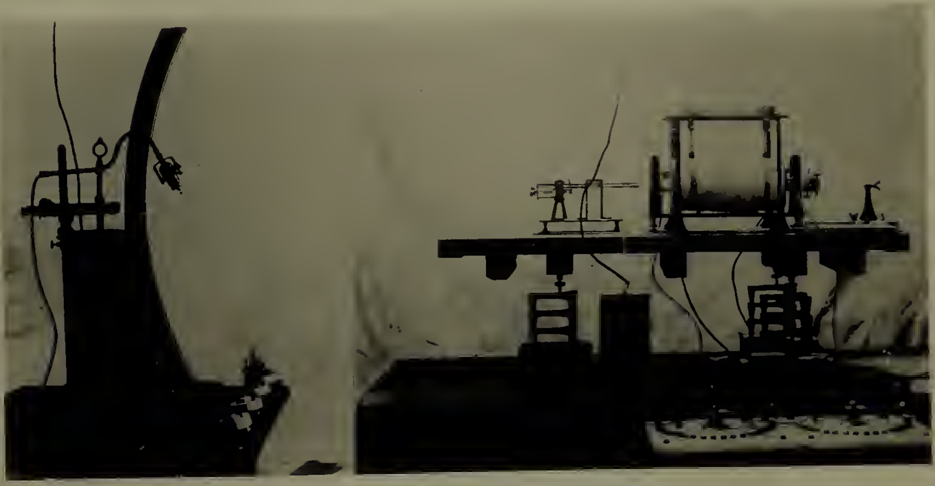
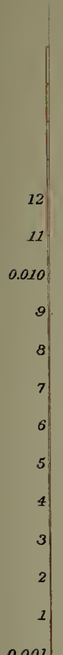


Fig. 24. General Arrangement.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Pl. IX.

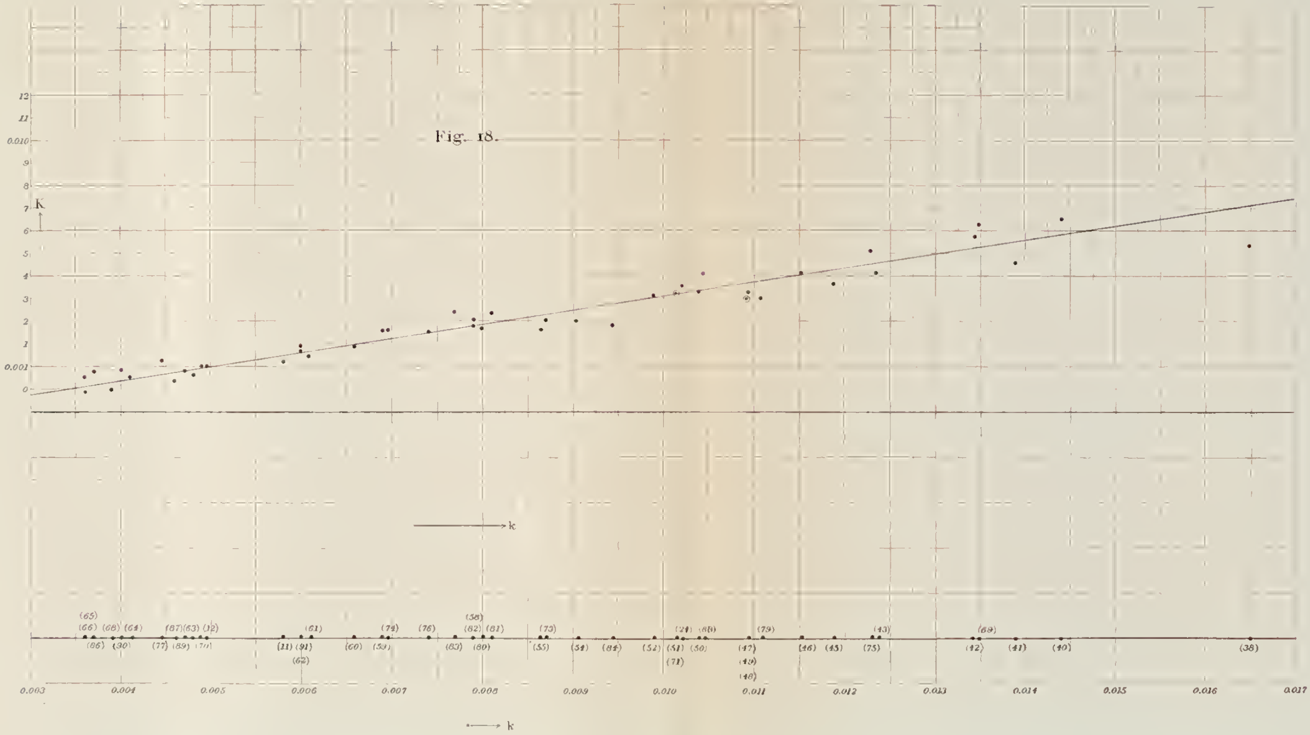
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Fig. 18.

Pl. X.

Fig. 19.

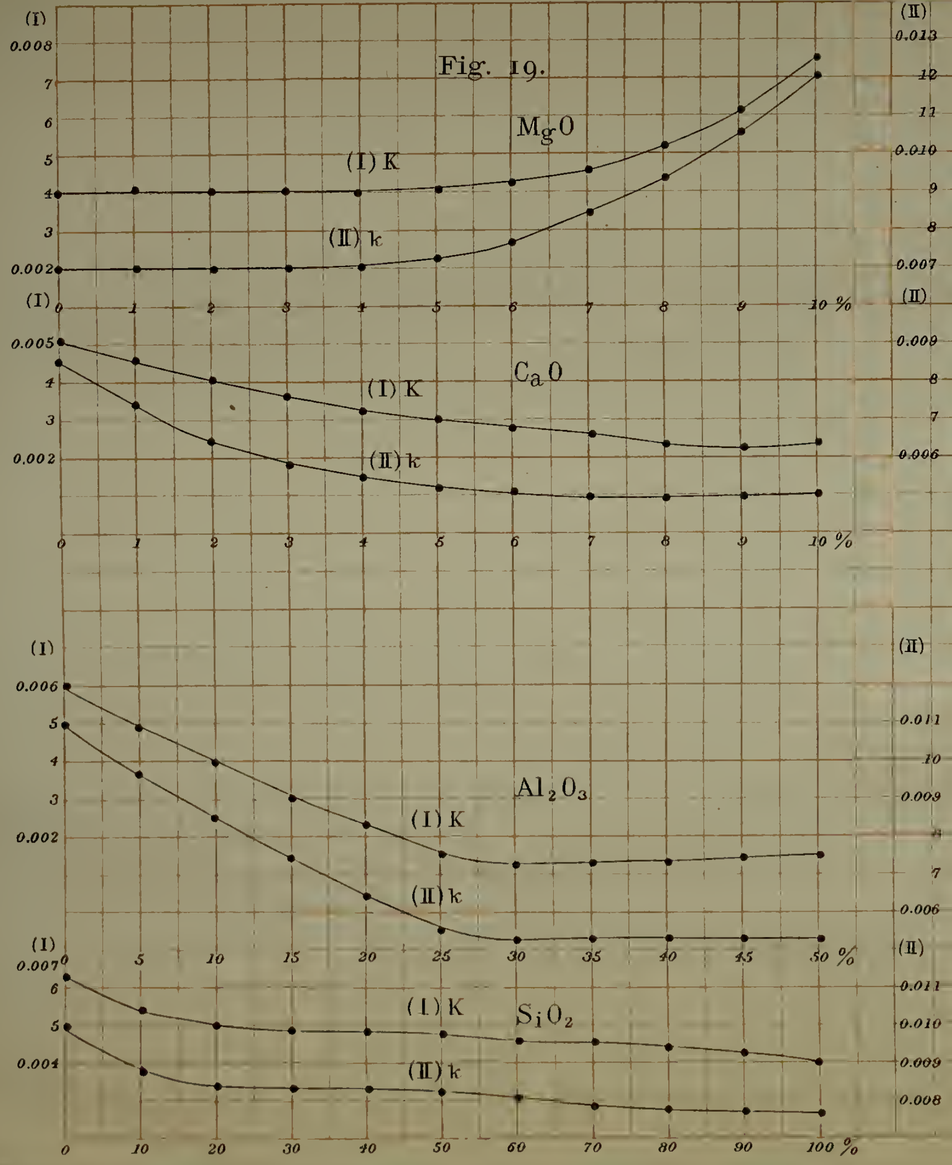
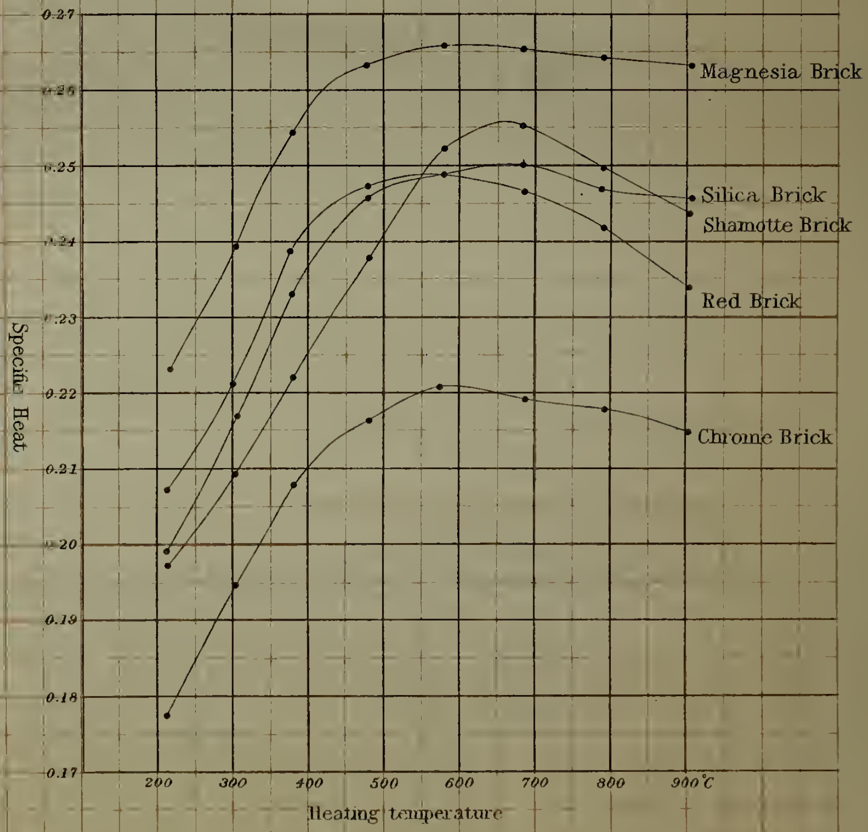


Fig. 20. Specific Heat. (Mean)



Pl. XI.

Fig. 25. Silica Brick

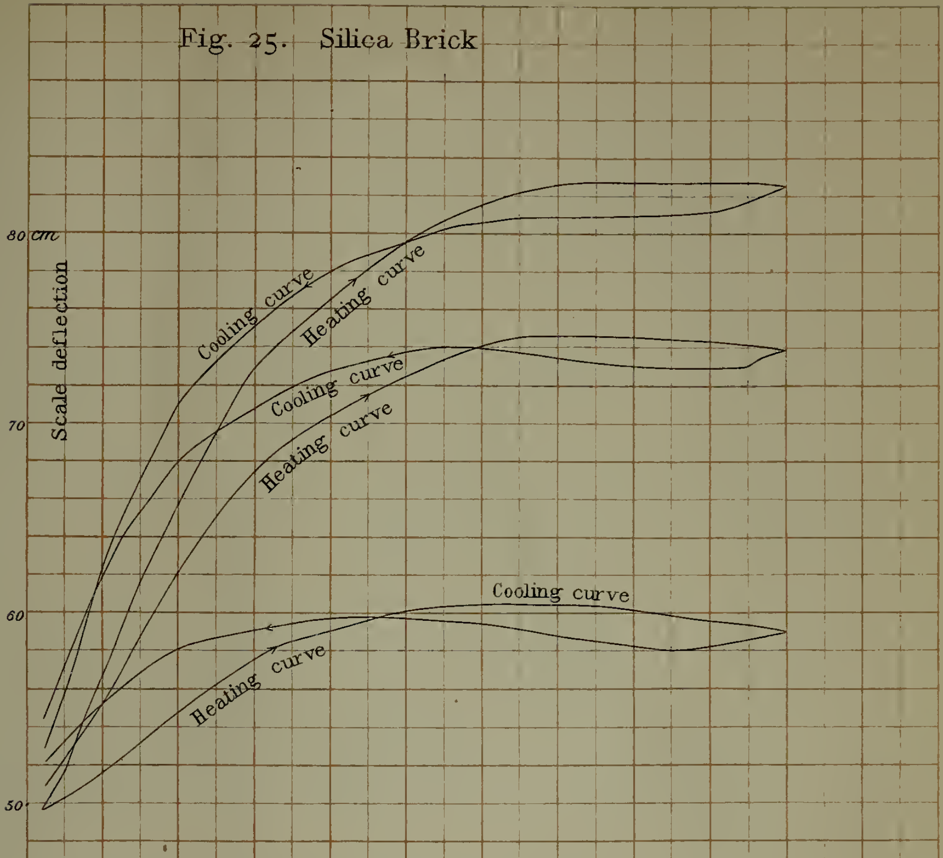
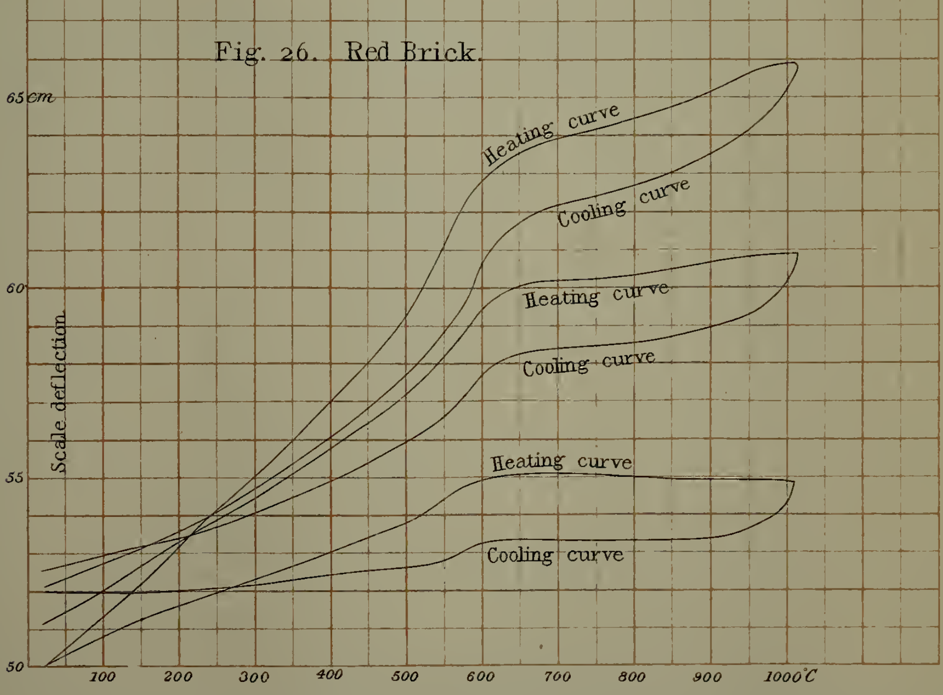


Fig. 26. Red Brick.



Pl. XII.

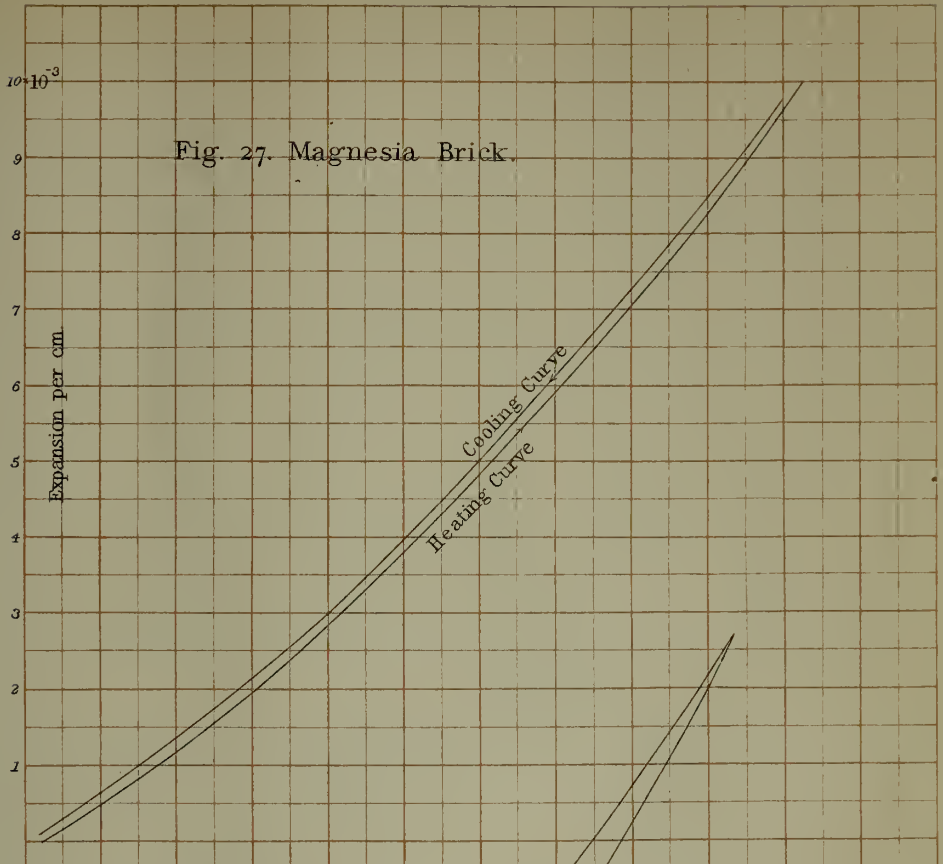


Fig. 27. Magnesia Brick.

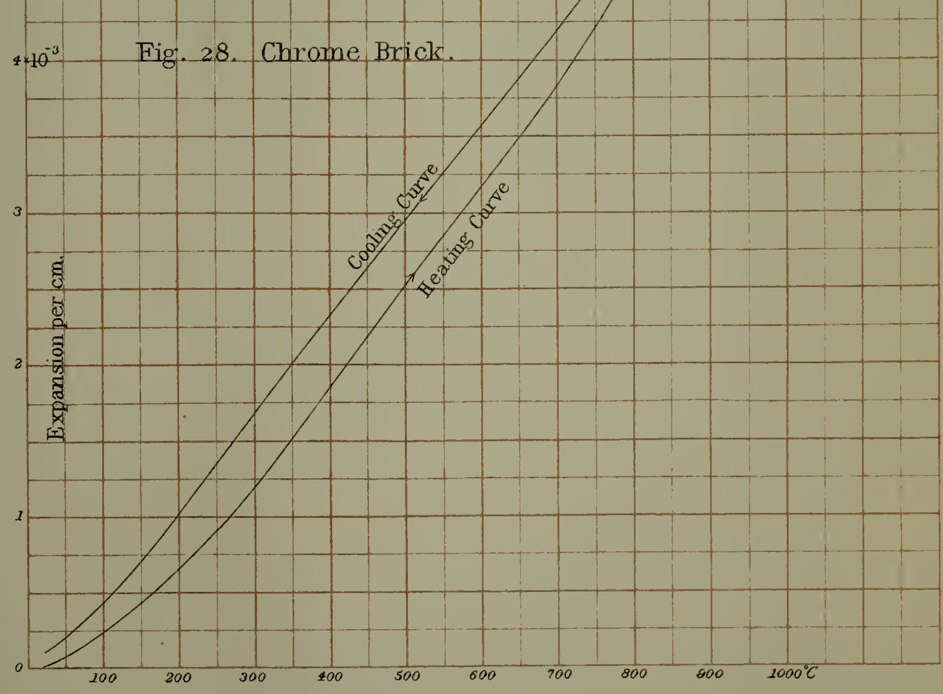


Fig. 28. Chrome Brick.

Pl. XIII.

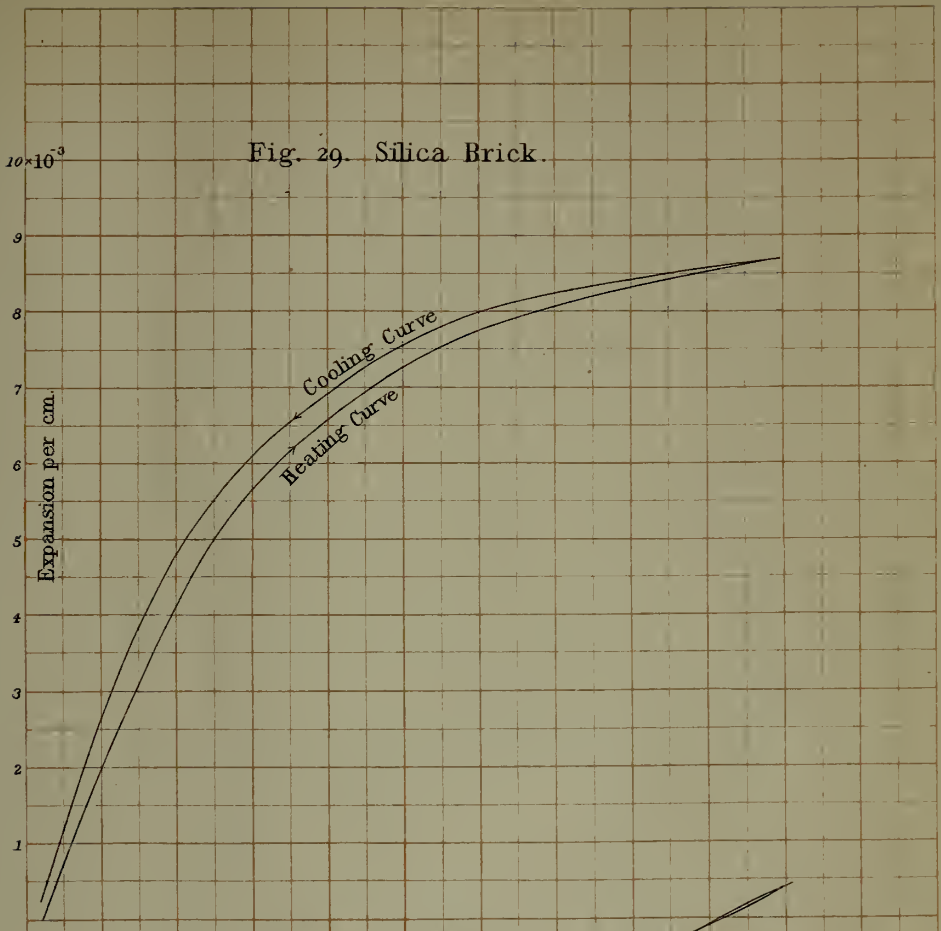


Fig. 29. Silica Brick.

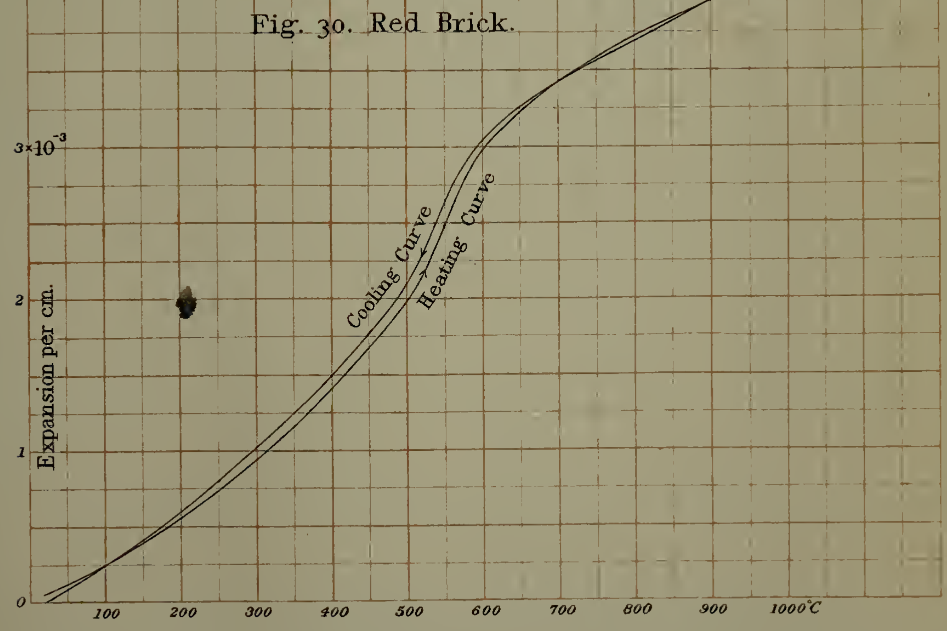


Fig. 30. Red Brick.

Pl. XIV.

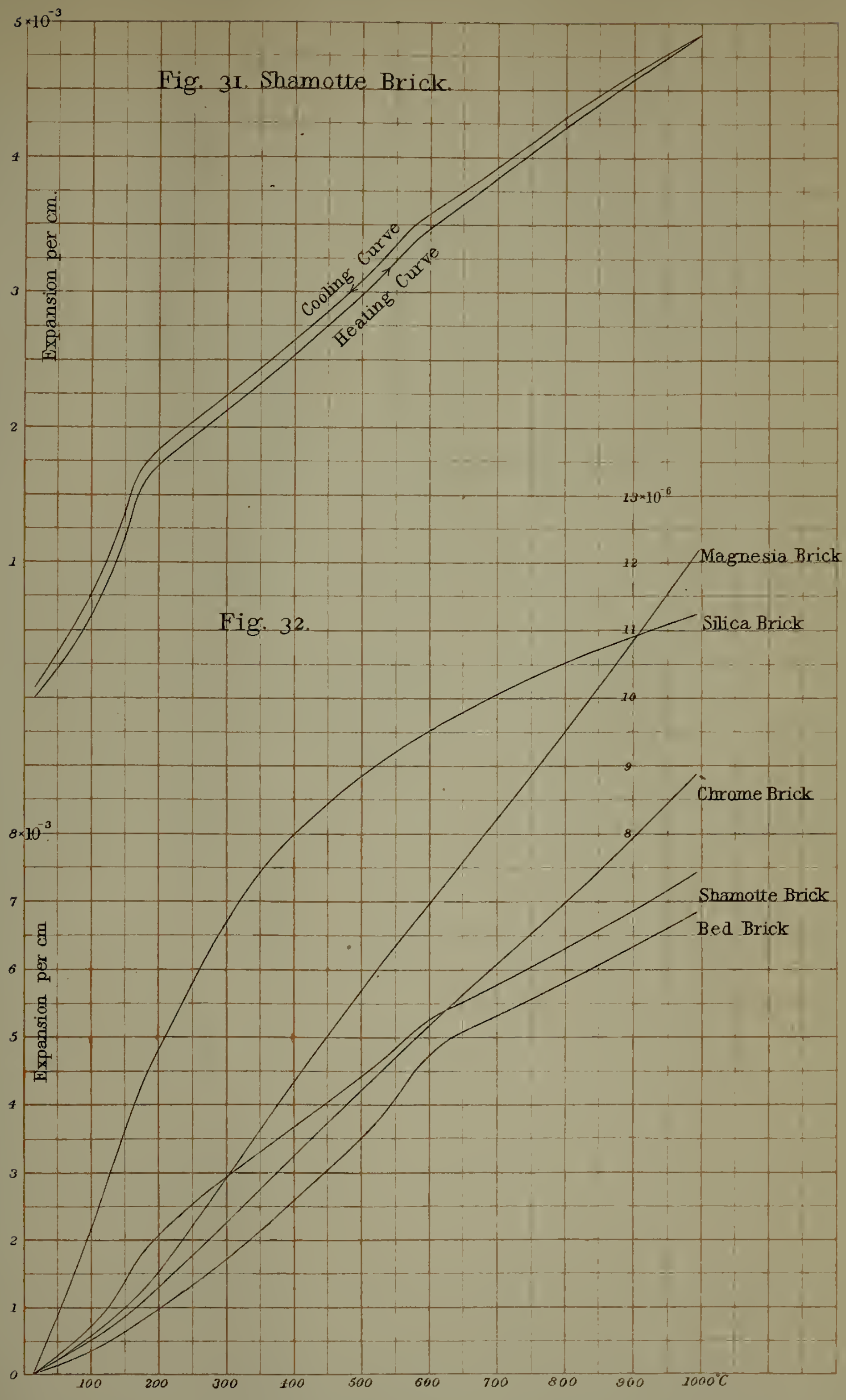


Fig. 31. Shamotte Brick.

Fig. 32.

Pl. XV.

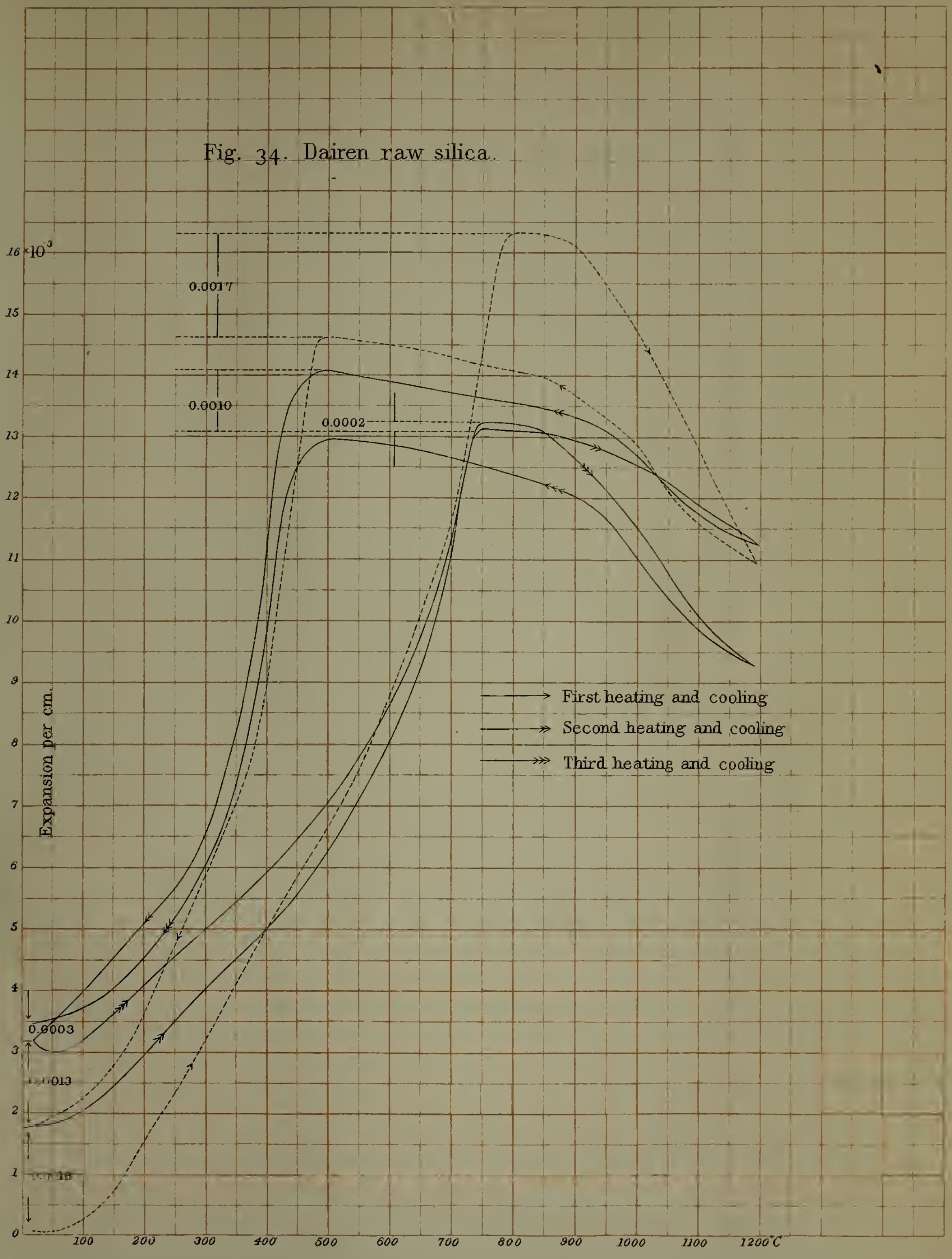


Fig. 34. Dairen raw silica.

Pl. XVI.

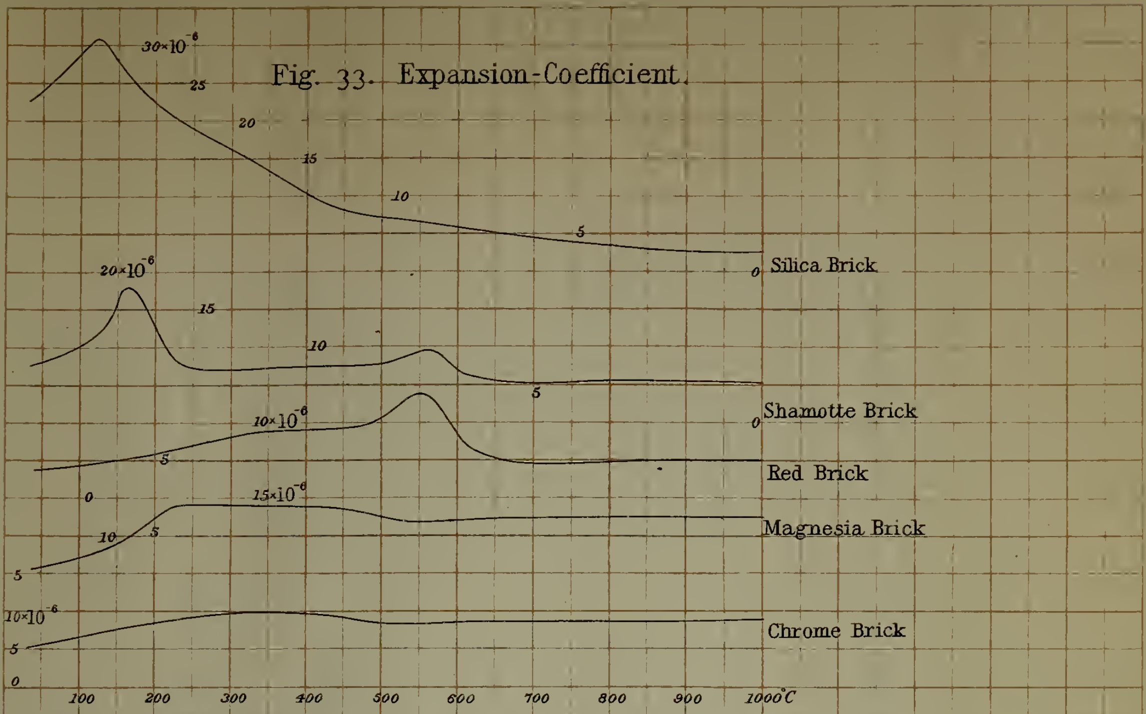


Fig. 33. Expansion-Coefficient.

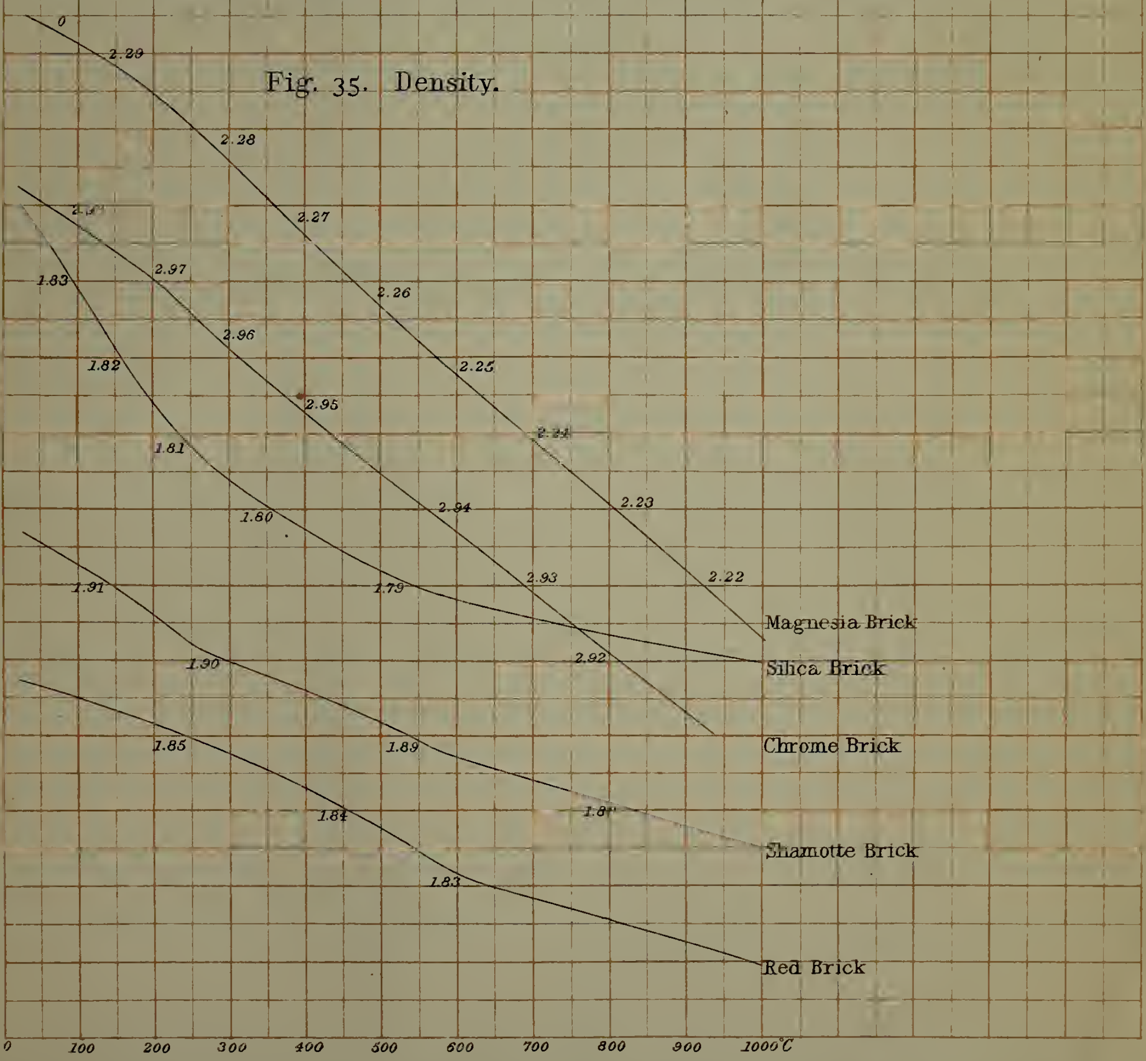


Fig. 35. Density.

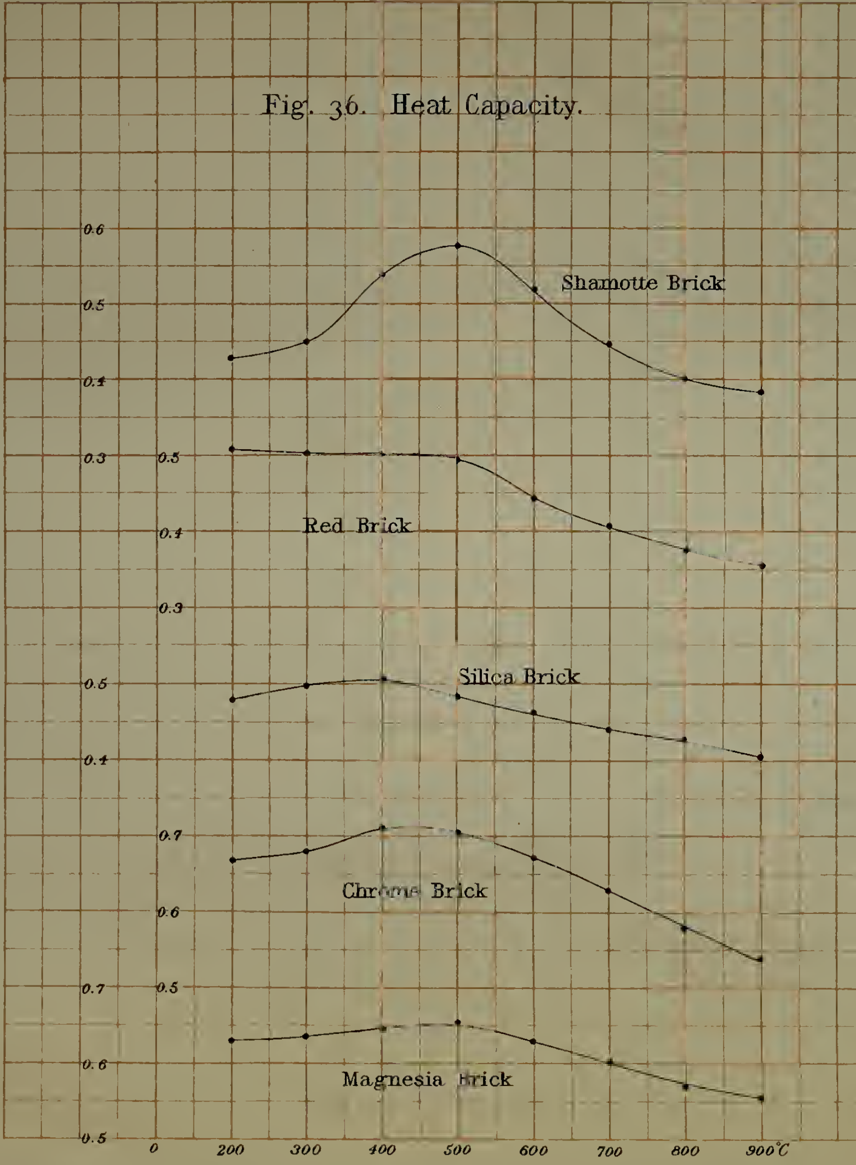


Fig. 36. Heat Capacity.

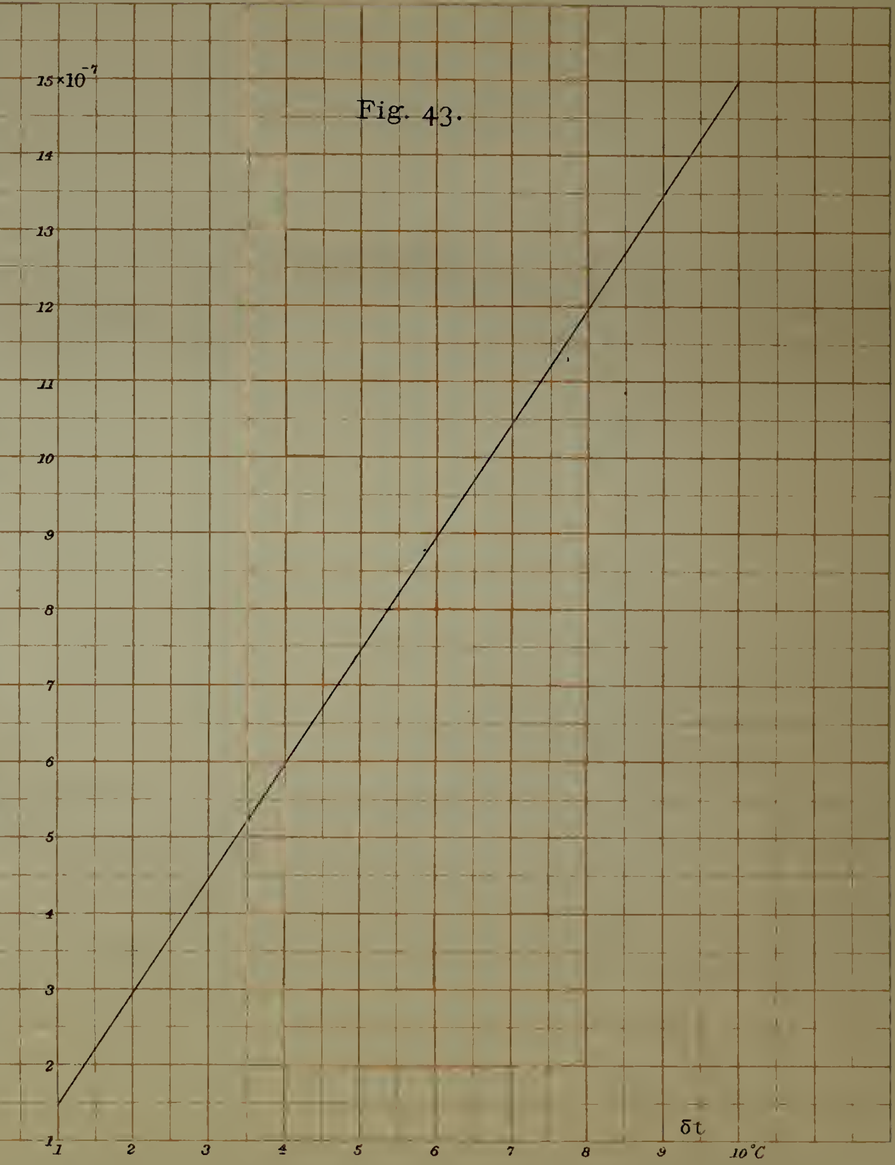


Fig. 43.

Pl. XVIII.

Fig. 44.

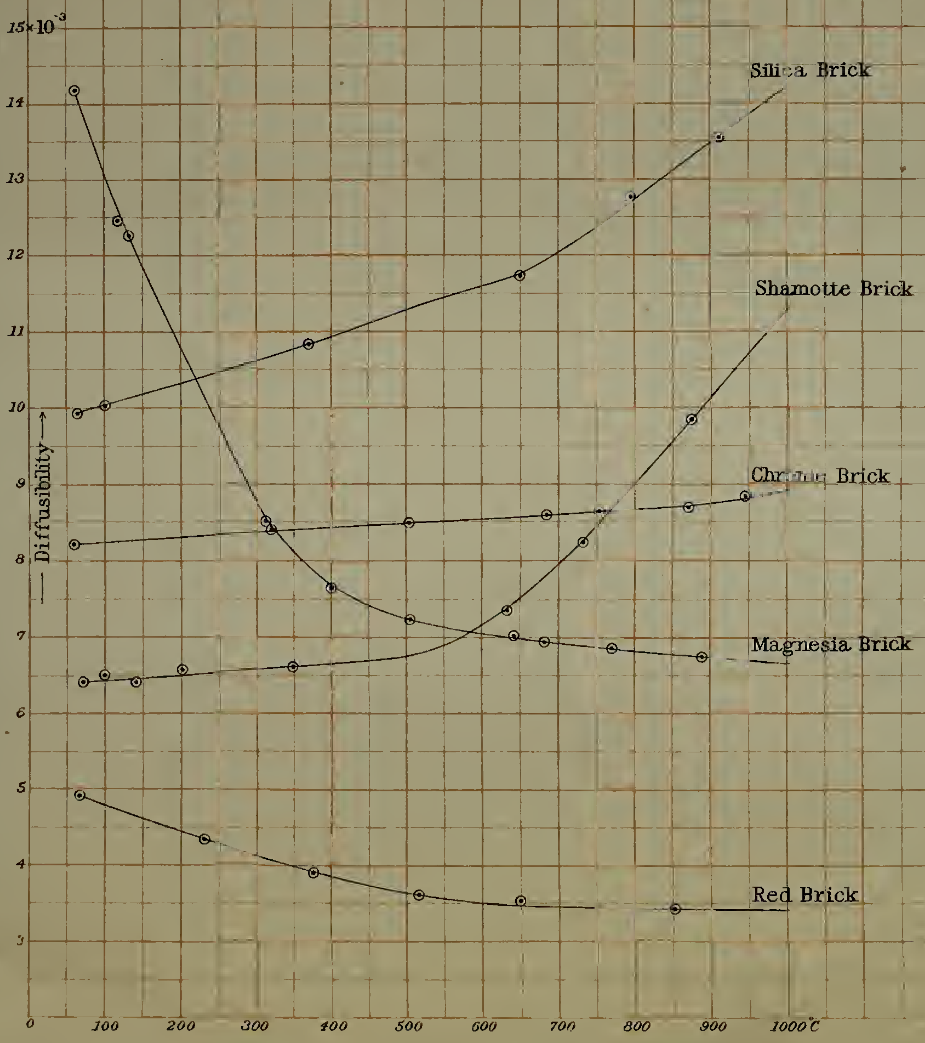
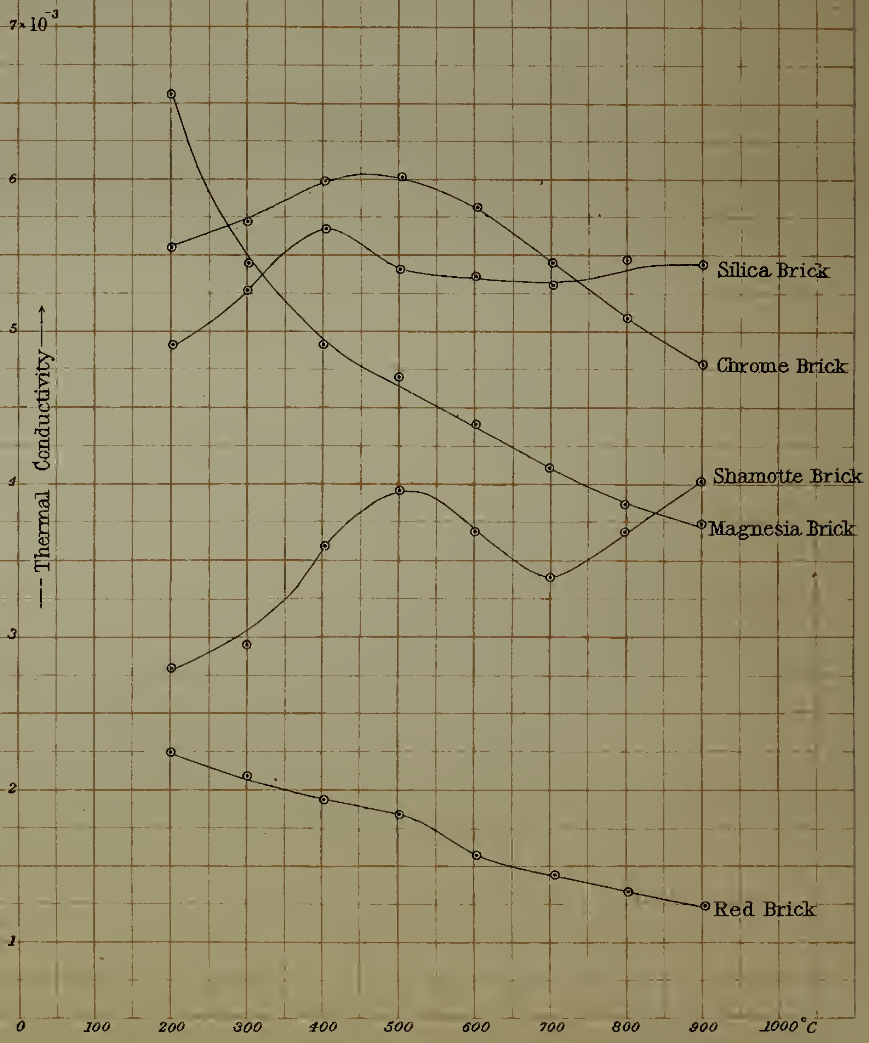


Fig. 45.



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